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BASELINE TESTS OF THE SEBRING CITI-VAN ELECTRIC DELIVERY TRUCK.(U)
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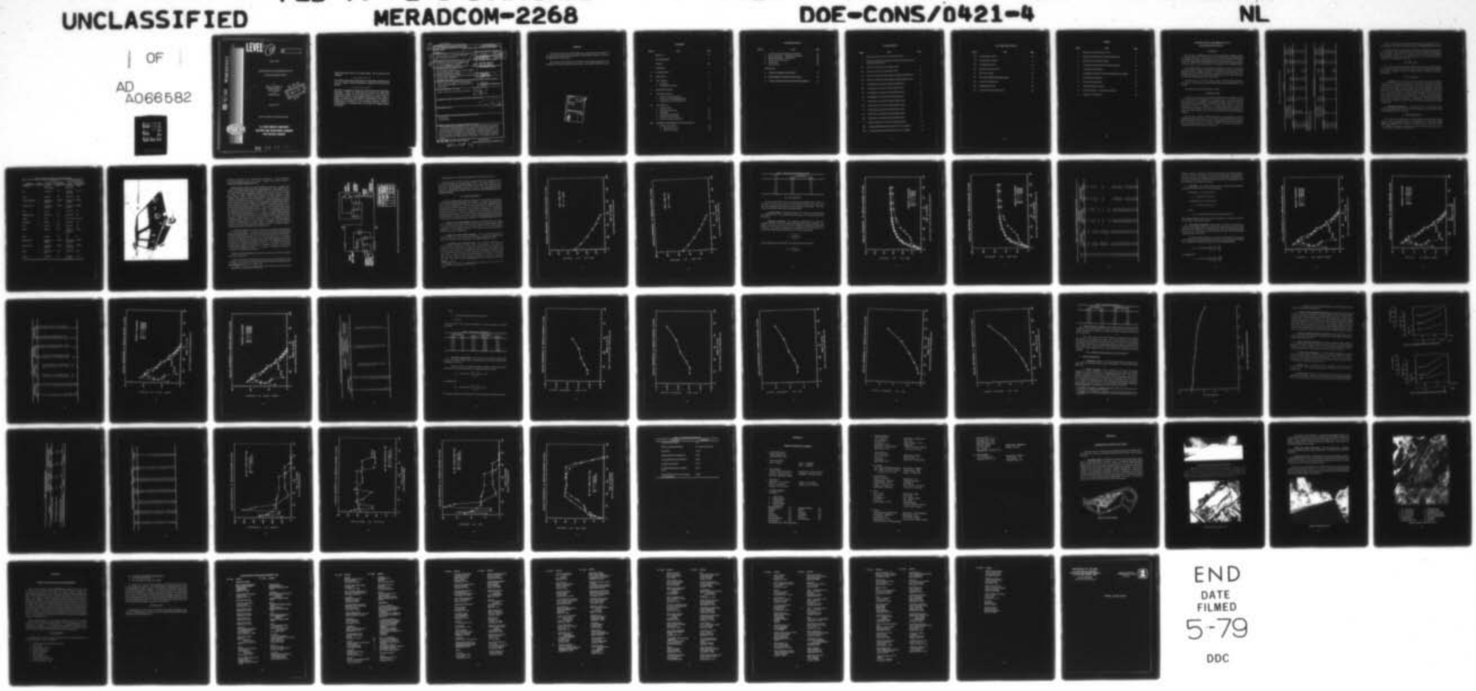

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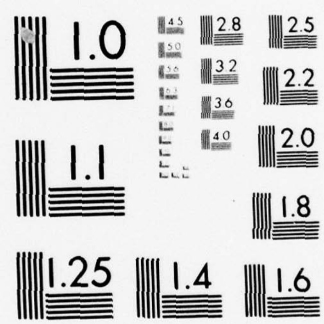
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Report 2268

BASELINE TESTS OF THE SEBRING CITI-VAN ELECTRIC DELIVERY TRUCK

by
Edward J. Dowgiallo, Jr.
Cornelius E. Bailey, Jr.
Ivan R. Snellings
and
William H. Blake

February 1979

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U.S. ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Citi-Van Model 611N0003, an electric two-passenger multipurpose van, was tested at the US Army Aberdeen Proving Ground test facilities in Aberdeen, Maryland, as part of a Department of Energy (DOE) project to characterize the state-of-the-art of electric vehicles. The Citi-Van is manufactured in Sebring, Florida, by Sebring Vanguard, Inc. It is powered by eight 6-volt batteries that are connected to the motor through a contactor control actuated by a foot pedal to control motor speed. The 6-horsepower motor drives the rear wheels through a direct drive to the differential. No regenerative braking was provided.

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PREFACE

The Electric and Hybrid Vehicle Program was conducted under the guidance of the (then) Energy Research and Development Administration (ERDA), now part of the Department of Energy (DOE).

The assistance and cooperation of US Postal Service is greatly appreciated. The Department of Energy provided funding support and guidance during this project.

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BASELINE TESTS OF THE SEBRING CITI-VAN ELECTRIC DELIVERY TRUCK

I. SUMMARY

The Citi-Van, a multipurpose electric vehicle manufactured in Sebring, Florida, by Sebring-Vanguard, Inc., was tested at the US Army Aberdeen Proving Ground test facilities in Aberdeen, Maryland, between 14 June and 13 July 1977. The tests are part of a Department of Energy (DOE) project to characterize the state-of-the-art of electric vehicles. This report presents the performance of the Sebring Citi-Van.

The Sebring Citi-Van is a two-passenger delivery truck with a cycolac plastic body and powered by eight 6-volt batteries. The batteries are connected to a motor through a contactor controller actuated by a foot pedal to control motor speed. The 6-horsepower motor drives the rear wheels through a direct drive to the differential. No regenerative braking was provided on this vehicle.

All tests were run at the gross vehicle weight of 884 kilograms (1949 lbm). The Citi-Van accelerated from 0 to 48.3 kilometers per hour (0 to 30 mi/h) in 21.5 seconds.

The results of the tests are summarized in Table 1.

II. INTRODUCTION

The vehicle tests and the data presented in this report are in support of Public Law 94-413 enacted by Congress on 17 September 1976. The Law requires the Energy Research and Development Administration (ERDA), now DOE, to develop data characterizing the state-of-the-art of electric and hybrid vehicles. The data so developed are to serve as a baseline (1) to compare improvements in electric and hybrid vehicle technologies, (2) to assist in establishing performance standards for electric and hybrid vehicles, and (3) to help guide future research and development activities.

The US Army Mobility Equipment Research and Development Command (MERADCOM) under the direction of the Electric and Hybrid Research Development and Demonstration Office of the Division of Transportation Energy Conservation of DOE has conducted track tests of electric vehicles to measure their performance characteristics and vehicle component efficiencies.

Table 1. Summary of Test Results for Citi-Van

(a) SI Units

Test Date	Test Condition (Constant Speed) (km/h); or Driving Schedule	Wind Velocity (km/h)	Temperature (°C)	Range (km)	Number of Cycles	Energy into Charger (MJ)	Indicated Energy Consumption (MJ/km)
29 Jun 77	48.0	17.7	28.9	43.9	–	55.8	1.27
30 Jun 77	48.0	12.9	26.7	46.0	–	55.8	1.21
1 Jul 77	40.0	8.0	26.4	56.8	–	57.6	1.01
5 Jul 77	40.0	6.4	29.4	55.2	–	55.8	1.01
12 Jul 77	B	0	25.6	42.2	120	61.2	1.45
13 Jul 77	B	6.4	22.2	47.0	130	59.4	1.26

Acceleration
0 to 30 km/h (20 mi/h) in 7 seconds
0 to 48 km/h (30 mi/h) in 22 seconds

(b) US Customary Units

Test Date	Test Condition (Constant Speed) (mi/h); or Driving Schedule	Wind Velocity (mi/h)	Temperature (°F)	Range (mi)	Number of Cycles	Energy into Charger (kWh)	Indicated Energy Consumption (kWh/mi)
29 Jun 77	30	11	84	27.3	–	15.5	0.57
30 Jun 77	30	8	80	28.6	–	15.5	0.54
1 Jul 77	25	5	79.5	35.3	–	16	0.45
5 Jul 77	25	4	85	34.3	–	15.5	0.45
12 Jul 77	B	0	78	26.2	120	17	0.65
13 Jul 77	B	4	72	29.2	130	16.5	0.57

The tests were conducted according to DOE Electric and Hybrid Vehicle Test and Evaluation Procedures, described in Appendix A of MERADCOM Report 2244.[1]

US customary units were used in the collection and reduction of data. The units were converted to the International System of Units (Systeme International, SI) for presentation in this report. US customary units are presented in parentheses. The parameters, symbols, units, and unit abbreviations used in this report are given in Table 2 for the convenience of the reader.

III. OBJECTIVES

The characteristics of interest for the Citi-Van are vehicle speed, range at constant speed, range over stop-and-go driving schedules, maximum acceleration, gradeability, road energy consumption, road power, indicated energy consumption, and battery characteristics.

IV. TEST VEHICLE

1. **Description.** The Citi-Van, an electric delivery truck, Model 611N0003, is a minivan in the 200-pound payload class. The compact vehicle has bench-type seating in front for a driver and one passenger. The body is composed of an all-aluminum frame and an ABS cycolac plastic shell. The vehicle is powered by eight 6-volt batteries that are located under the bench-type seat. The batteries are connected to the series motor through a contactor controller actuated from a foot pedal. The motor is connected directly to the differential. The battery, contactor controller, and 4.5-killowatt d.c. motor are connected in series. The vehicle is shown in Figure 1 and described in detail in Appendix A. A single-phase, 115-volt on-board battery charger is used to charge the traction batteries. No regenerative braking was provided on this vehicle.

2. **Operating Characteristics.** A key switch is used to close the main switch which enables the contactor controller, which is actuated by a foot throttle, to change the voltage applied to the 4.5-kw motor.

V. INSTRUMENTATION

The Citi-Van was instrumented to measure vehicle speed and range, battery voltage, current, instantaneous power, and averaged power. The battery charger input in a.c. kilowatt-hours and output in d.c. amperes were also measured. Battery

[1] E. J. Dowgiallo, Jr.; C. E. Bailey, Jr.; I. R. Snellings; and W. H. Blake; "Baseline Tests of the EVA Metro Electric Passenger Vehicle," MERADCOM Report 2244 (July 1978).

Table 2. Parameters, Symbols, Units, and Unit Abbreviations

Parameter	Symbol	SI Units		U.S. Customary Units	
		Unit	Abbreviation	Unit	Abbreviation
Acceleration	a	meter per second squared	m/s^2	mile per hour per second	mi/h/s
Area	–	square meter	m^2	square foot; square inch	ft^2; $in.^2$
Energy	–	megajoule	MJ	kilowatt hour	kWh
Energy Consumption	E	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mi
Energy Economy	–	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mi
Force	F	newton	N	pound force	lbf
Integrated current	–	ampere hour	Ah	ampere hour	Ah
Length	–	meter	m	inch; foot; mile	in.; ft; mi
Mass; weight	w	kilogram	kg	pound mass	lbm
Power	P	kilowatt	kW	horsepower	hp
Pressure	–	kilopascal	kPa	pound force per square inch	lbf/in^2
Range	–	kilometer	km	mile	mi
Specific energy	–	megajoule per kilogram	MJ/kg	watt hour per pound mass	Wh/lbm
Specific power	–	kilowatt per kilogram	kW/kg	kilowatt per pound mass	kW/lbm
Speed	V	kilometer per hour	km/h	mile per hour	mi/h
Volume	–	cubic meter	m^3	cubic inch; cubic foot	$in.^3$; ft^3

Figure 1. Partial Side and Front View of the Sebring Citi-Van.

electrolyte temperatures were measured with thermometers. A brief description of the instrumentation system is given below. Details on the recorder are given in Appendix B of MERADCOM Report 2244.[2]

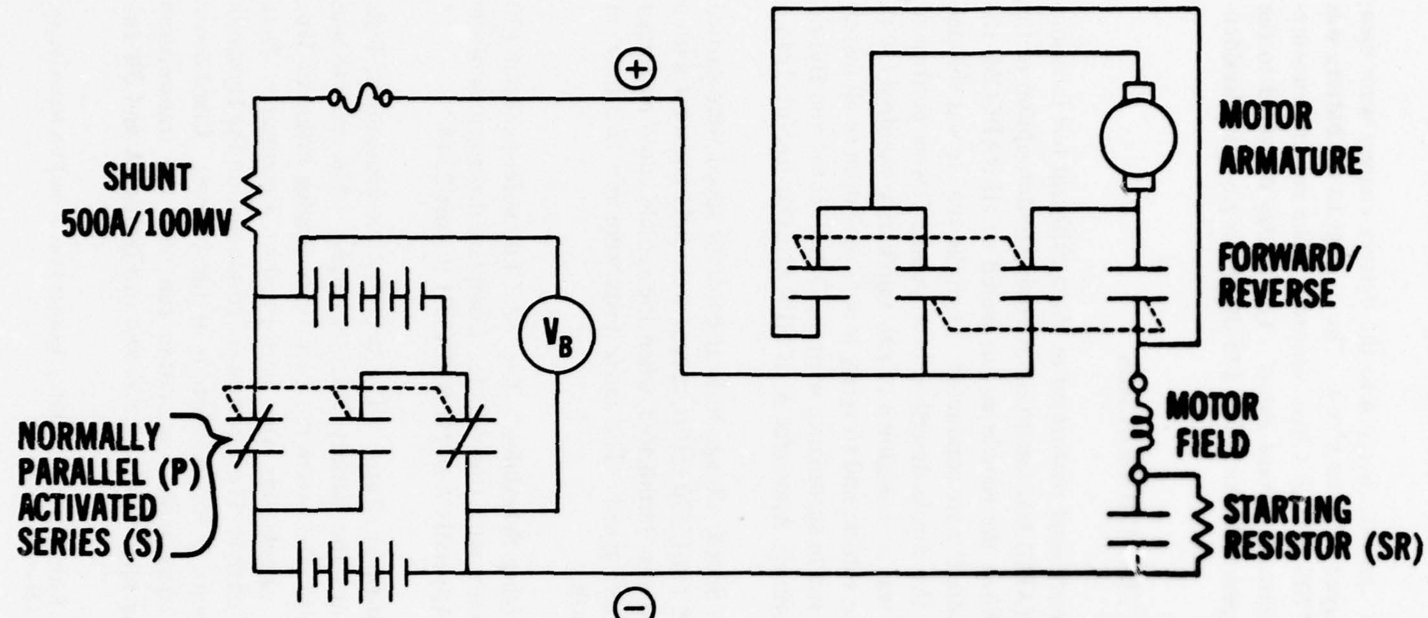
Instrumentation consisted of signal conditioning circuits and a magnetic tape recorder for recording analog signals of electrical parameters. The magnetic tape recorder was operated in the frequency modulation mode at 4.763 cm (1.875 inches) per second. The signal conditioning circuitry to the recorder consisted of a main battery voltage divider, a shunt-voltage amplifier for current monitor, an analog multiplier, and averager circuits for averaging power and current since the recorder response was less than 0.3 db down at 500 Hertz. A voltage proportional to battery power was produced by the instantaneous multiplication of voltages proportional to battery voltage and current. Voltages proportional to current and power were recorded both raw and electronically averaged. The raw values include the rapid switching transients associated with the solid state controller. An estimation of the overall d.c. measurement error is less than ± 1.8% for power. This includes digitization from the field recorded analog magnetic tape to a computer compatible digitized magnetic tape. The measurement error of the various conditioning circuits can be broken down as follows: current shunt (± 0.25%), current amplifier (± 1%), multiplier (± 0.25%), and magnetic tape recorder (± 1%). In addition to these errors, phase deterioration starts to be significant above 3 kilohertz when the multiplier is combined with an averager (± 1%); and, finally, the analog-to-digital converter at 16 bits and 100 conversions per second did not introduce any significant error.

A schematic diagram of the electric propulsion system with the instrumentation sensors is shown in Figure 2. A Laboratory Equipment Corporation, Tracktest Fifth Wheel with the Model DD1.1, Electronics Digital Speed Meter and the Model DD2.1, Electronic Digital Distance Meter were used during the track tests. A tachometer generator was connected to the fifth wheel to record velocity and calculate distance traveled. The fifth wheel and auxiliaries weighed about 18.6 kilograms (41 lb). The fifth wheel was calibrated by rotating the wheel on a constant-speed fifth-wheel calibrator drum mounted on the shaft of a synchronous AC motor. The accuracies of the velocity readings were within ± ½% of reading. Velocity was recorded on a Lockheed Store 7 Magnetic Tape Recorder.

Battery electrolyte temperatures and specific gravities were measured manually before and after the tests.

Power for the fifth wheel instruments was provided by a vehicle auxiliary 12-volt SLI battery. The power for the magnetic tape recorder and signal conditioning instrument package was supplied from a battery pack.

[2] E. J. Dowgiallo, Jr.; C. E. Bailey, Jr.; I. R. Snellings; and W. H. Blake; "Baseline Tests of the EVA Metro Electric Passenger Vehicle," MERADCOM Report 2244 (July 1978).



OPERATING SEQUENCE		
STEP	MODE	BATTERY VOLTAGE
1	P&SR	24 VOLTS
2	P	24 VOLTS
3	S	48 VOLTS

Figure 2. Schematic Diagram of Vehicle Electric Propulsion System Showing Instrumentation Monitors.

All instruments were calibrated periodically with checks before each test.

The current into the battery and the energy into the battery charger were measured while the battery was recharged after each test. The current to the battery was recorded on a Hewlett Packard 7100 B Strip Chart Recorder. The current measurement used a 100 amperes-100 milivolts current shunt. The energy delivered to the charger was measured with a Sangamo Electric Type J4S 30TA Single-Phase Residential Watt-Hour Meter.

VI. TEST PROCEDURES

The tests decribed in this report were performed at three different test locations at the Aberbeen Proving Ground (APG) test facilities. A complete description of the track is given in Appendix B. When the vehicle was delivered to MERADCOM, the pretest checks described in Appendix C were conducted. Then the vehicle was shipped to Aberdeen Proving Ground and the checks described in Appendix C were performed before the first test run. There was a shakedown run to familiarize the driver with the operating characteristics of the vehicle and to verify proper operation of all instrumentation systems. All tests were run in accordance with the DOE Electric and Hybrid Vehicle Test and Evaluation Procedure, Appendix A of MERADCOM Report 2244.[3]

1. **Range Test at Constant Speed.** Range tests at constant speed were carried out at 40 km/h (25 mi/h) and 48 km/h (30 mi/h); speeds were held constant within ± 1.6 km/h (1 mi/h) and the test was terminated when the vehicle could no longer maintain 95% of the designated test speed. The range tests were run two times at 40 km/h and two times at 48.0 km/h.

2. **Range Tests Under Driving Schedules.** The 32.2 kilometer-per-hour (20 mi/h), schedule B, was run two times with this vehicle. Complete descriptions of the cycle test procedures are given in Appendix A of MERADCOM Report 2244.[4]

3. **Acceleration and Coast-Down Tests.** The acceleration coast-down tests were performed continuously until the battery was discharged. The vehicle was operated in this manner two times. Data were recorded on an analog magnetic tape recorder and, later, digitized and calculations were performed on a computer. Data were tabulated for three states of charge. These tests were conducted on the Dynamometer Course at APG (see Appendix B for description of the course). Coast-down data were taken following each maximum acceleration run with the transmission in neutral. The speed versus time relationships are shown in Figures 3A and 3B and Table 3.

[3] E. J. Dowgiallo, Jr.; C. E. Bailey, Jr.; L. R. Snellings; and W. H. Blake; "Baseline Tests of the EVA Metro Electric Passenger Vehicle," MERADCOM Report 2244 (July 1978).

[4] Ibid.

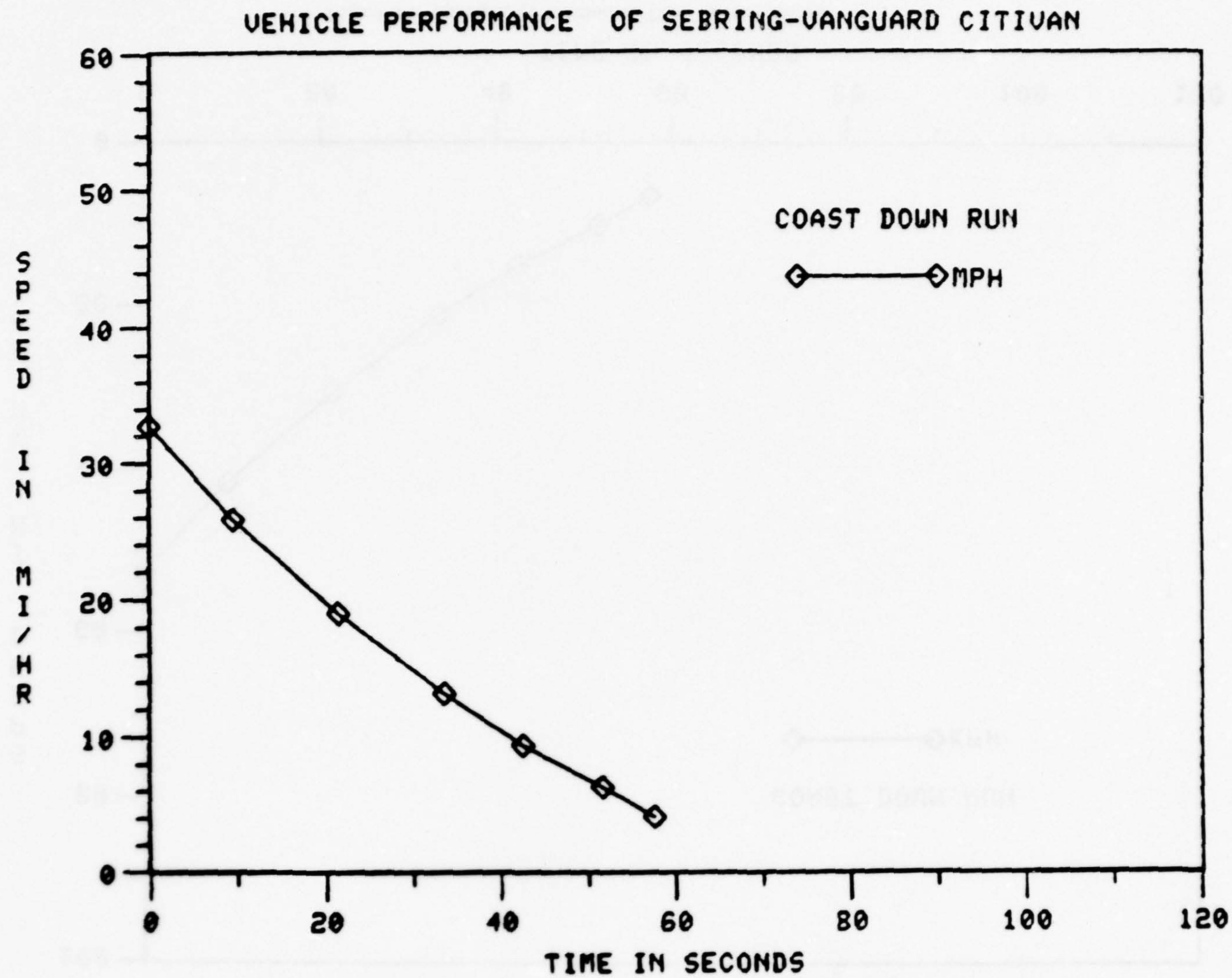


Figure 3A. Speed as a Function of Time (English Units).

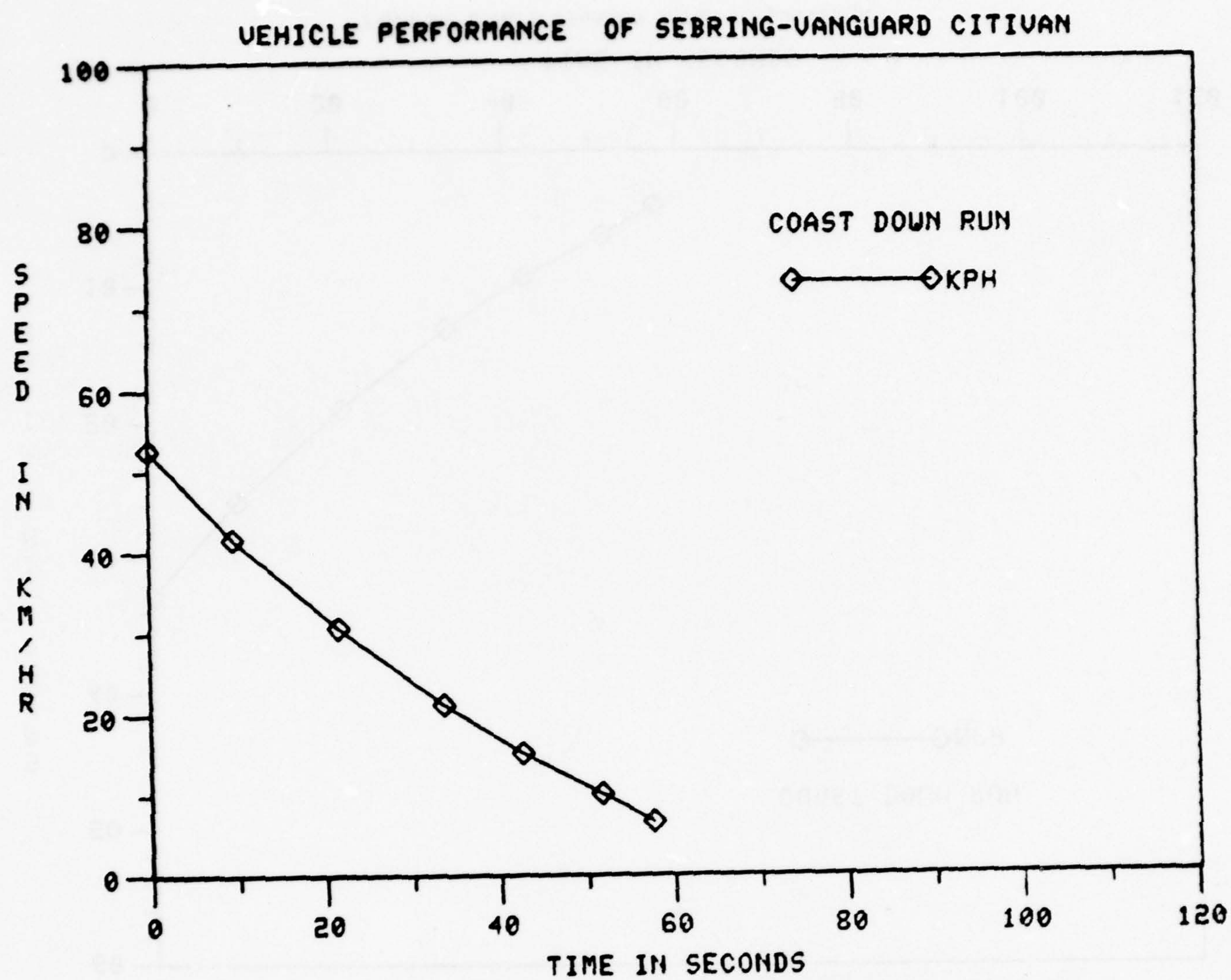


Figure 3B. Speed as a Function of Time (Metric Units).

Table 3. Speed Versus Time During Coasting

Time	Vehicle Speed	
(s)	(km/h)	(mi/h)
0	52.6	32.7
9.6	41.6	25.8
21.6	30.6	19.0
33.6	21.2	13.2
42.6	15.2	9.4
51.6	10.1	6.3
57.6	6.6	4.1

VII. TEST RESULTS

The data collected from all the range tests are summarized in Table 1. Shown in the table are the test data, type of test, environmental conditions, the range test results, the temperature of the battery, and the energy into the charger. These data are used to determine vehicle range and energy economy.

1. **Maximum Speed.** The maximum speed of the vehicle was measured during the acceleration tests. The measured maximum speed was 52.5 km/h (32.6 mi/h) for this vehicle.

2. **Maximum Acceleration.** The maximum acceleration of the vehicle was measured with the batteries fully charged, 40% discharged, and 80% discharged. The results of the tests are shown in the curves of Figures 4A and 4B and are tabulated in Table 4. The average acceleration, $\overline{a}_n$, was calculated for the time period t_{n-1} to t_n where the vehicle speed increased from V_{n-1} to V_n from the equation:

$$a_n = \frac{V_n - V_{n-1}}{t_n - t_{n-1}}$$

and the average speed of the vehicle, $\overline{V}$, was calculated from the equation:

$$\overline{V} = \frac{V_n + V_{n-1}}{2}$$

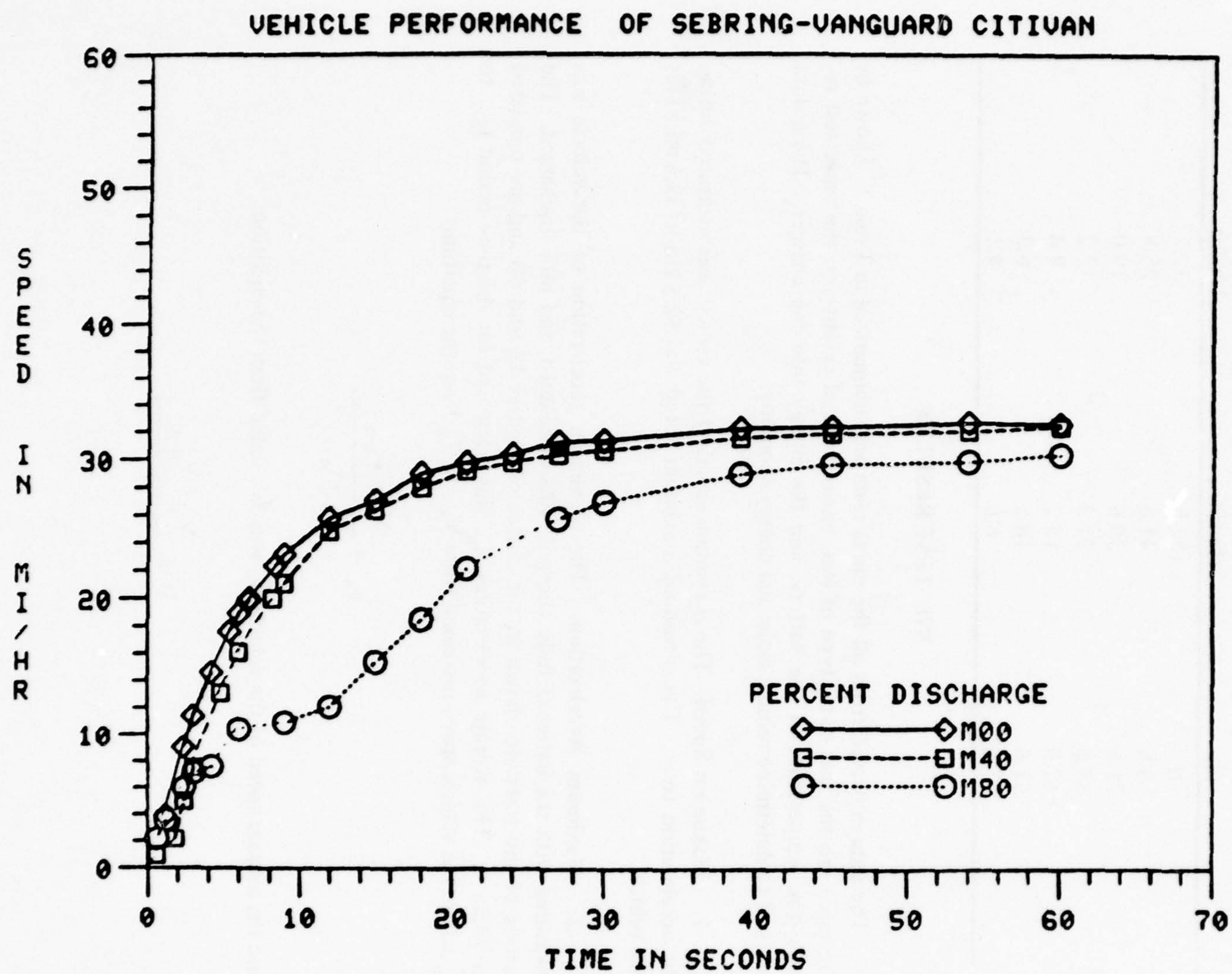


Figure 4A. Speed as a Function of Time During Acceleration (English Units).

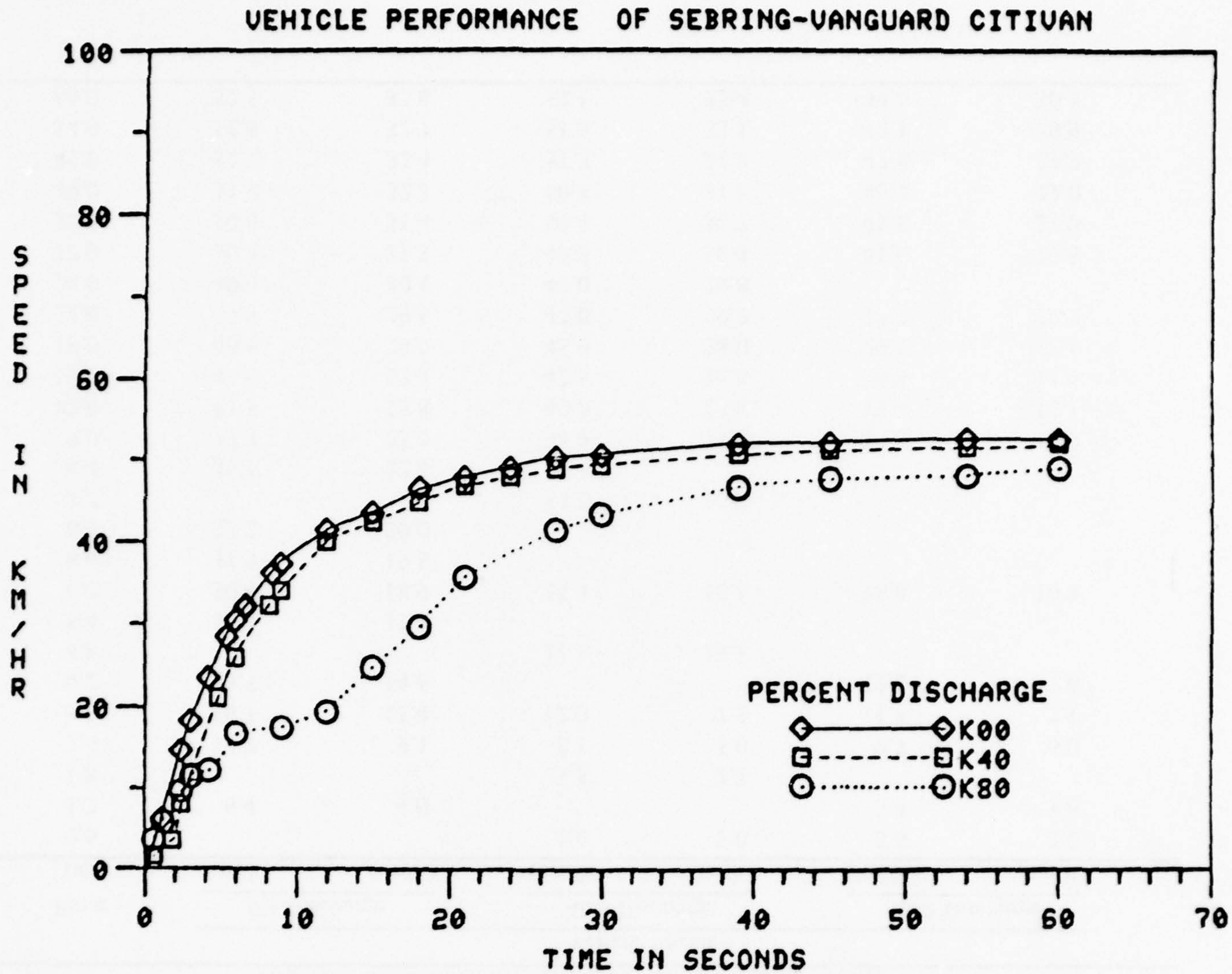


Figure 4B. Speed as a Function of Time During Acceleration (Metric Units).

Table 4. Acceleration Test Results at Three States of Charge

Time	Vehicle Speed					
	0% Discharge		40% Discharge		80% Discharge	
(s)	(km/h)	(mi/h)	(km/h)	(mi/h)	(km/h)	(mi/h)
0.6			1.6	1.0	3.6	2.2
1.2	6.4	4.0			5.8	3.6
1.8			3.5	2.2		
2.4	14.7	9.1	8.1	5.0	9.7	6.0
3.0	18.3	11.4	12.0	7.5	11.4	7.1
4.2	23.5	14.6			12.2	7.6
4.8			21.1	13.1		
5.4	28.4	17.6				
6.0	30.4	18.9	25.9	16.1	16.8	10.4
6.6	31.9	19.8				
6.7	32.2	20.0				
8.2			32.2	20.0		
8.4	36.1	22.4				
9.0	37.3	23.2	34.0	21.1	17.5	10.9
12.0	41.5	25.8	40.0	24.9	19.4	12.1
15.0	43.6	27.1	42.5	26.4	24.8	15.4
18.0	46.6	29.0	45.0	28.0	29.7	18.5
21.0	47.9	29.8	47.0	29.2	35.7	22.2
24.0	49.0	30.4	48.0	29.8		
27.0	50.3	31.3	49.0	30.4	41.6	25.8
30.0	50.6	31.4	49.4	30.7	43.5	27.0
39.0	51.9	32.3	50.8	31.6	46.7	29.0
45.0	52.1	32.4	51.3	31.9	47.8	29.7
54.0	52.6	32.7	51.6	32.1	48.1	29.9
60.0	52.5	32.6	52.1	32.4	49.0	30.4

Average acceleration as a function of speed is shown in Figures 5A and 5B and Table 5. These tests were run consecutively and the percent of discharge was determined by computer calculation. Discharging the battery by continuous start-stop vehicle operation rather than allowing a cool-off period while the battery was discharged to each state of charge was considered more realistic.

3. **Gradeability**. The maximum vehicle speed on a specific grade is determined from maximum acceleration tests by using the equations:

Gradeability, G, at a speed $\overline{V}$, in km/h:

$$G = 100 \tan (\sin^{-1} 0.1026\, \overline{a}_n)\ \%$$

or in English units at a speed $\overline{V}$ in mi/h:

$$G = 100 \tan (\sin^{-1} 0.0455\, \overline{a}_n)\ \%$$

where:

$\overline{a}_n$ = acceleration in meters per second squared (mi/h/s).

The resulting maximum grade the Citi-Van can negotiate as a function of speed is shown in Figures 6A and 6B and Table 6.

4. **Road Energy Consumption.** Road energy is a measure of the energy consumed in overcoming the vehicle's aerodynamic and rolling resistance plus the energy consumed in the differential drive shaft and the portion of the transmission rotating when in neutral. Road energy is obtained during coast-down with the differential being driven only by the wheels.

The road energy consumed by the vehicle at various speeds and the losses in the differential were determined from coast-down tests. Road energy consumption (E_n) is calculated as megajoules per kilometer from the following equation:

$$E_n = 2.78 \times 10^{-4} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \frac{MJ}{km}$$

or in English units:

$$E_n = 9.07 \times 10^{-5} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \frac{kWh}{mi}$$

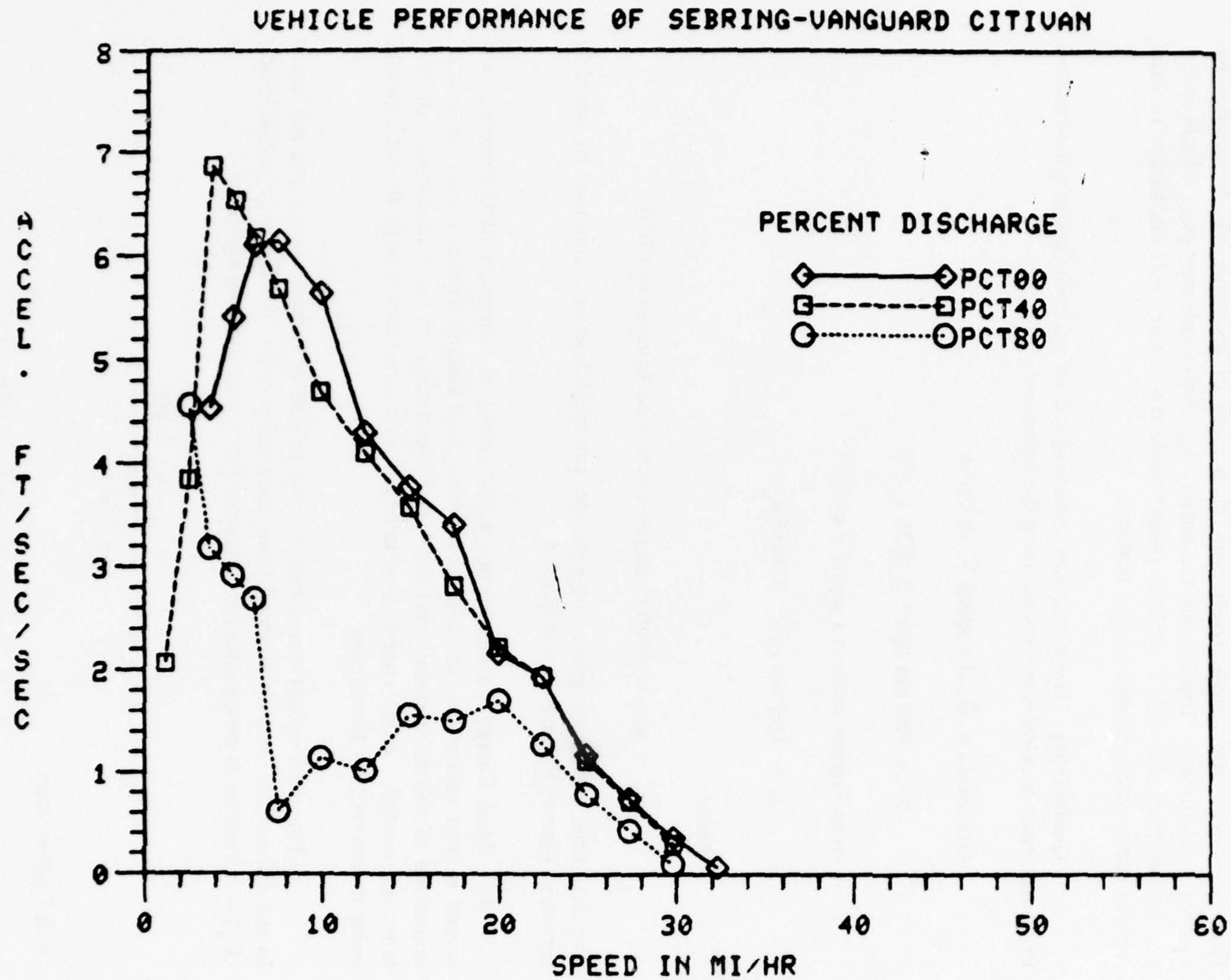


Figure 5A. Acceleration as a Function of Speed (English Units).

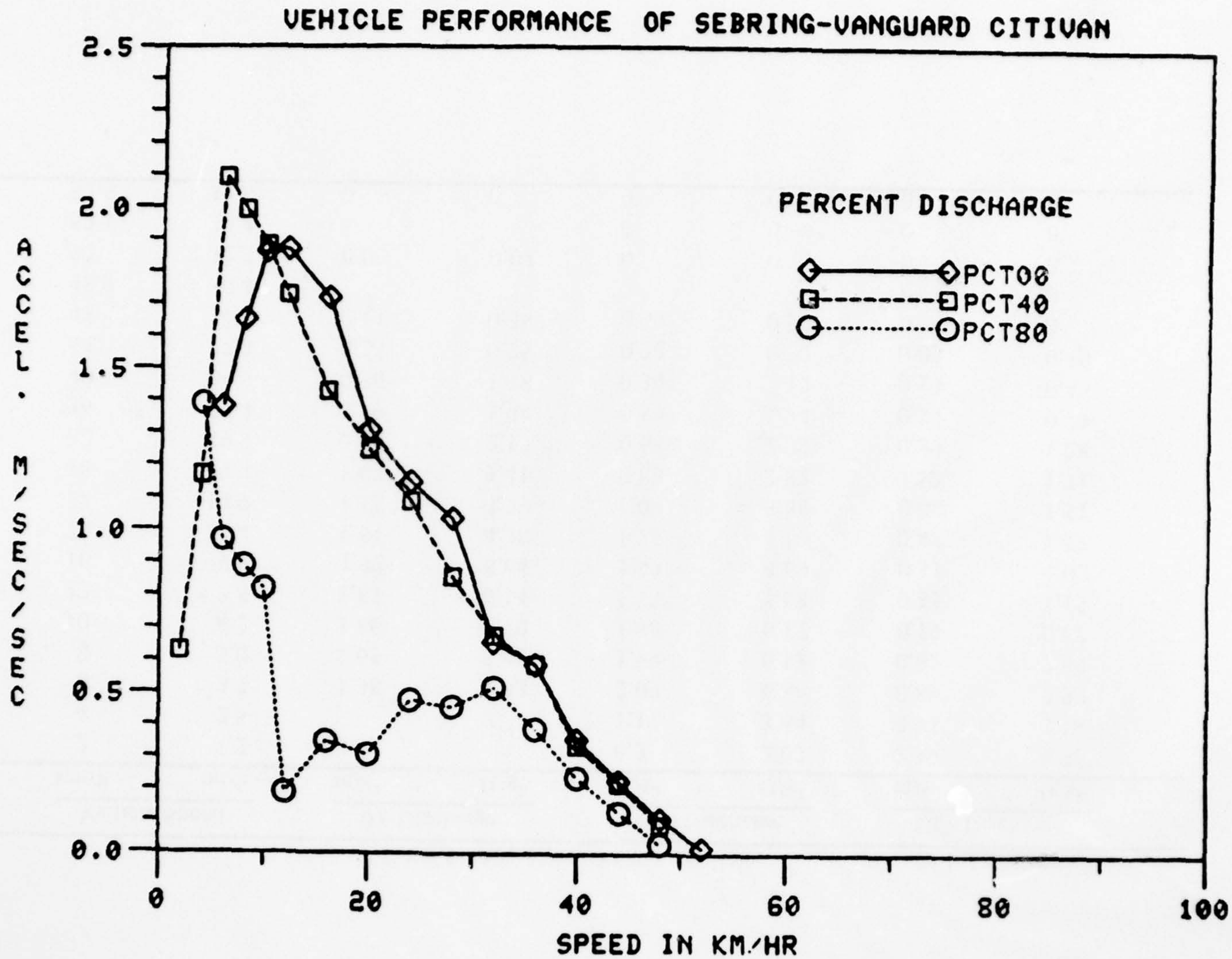


Figure 5B. Acceleration as a Function of Speed (Metric Units).

Table 5. Acceleration Characteristics

Vehicle Speed		0% Discharge		40% Discharge		80% Discharge	
km/h	mi/h	m/s^2	ft/s^2	m/s^2	ft/s^2	m/s^2	ft/s^2
2	1.2			6.3	2.07	1.39	4.56
4	2.5			1.17	3.84	0.97	3.18
6	3.7	1.38	4.53	2.09	6.86	0.89	2.92
8	5.0	1.65	5.41	1.99	6.53	0.82	2.69
10	6.2	1.86	6.10	1.88	6.17	0.19	0.62
12	7.5	1.87	6.14	1.73	5.68	0.35	1.15
16	9.9	1.72	5.64	1.43	4.69	0.31	1.02
20	12.4	1.31	4.30	1.25	4.10	0.48	1.57
24	14.9	1.15	3.77	1.09	3.58	0.46	1.51
28	17.4	1.04	3.41	0.86	2.82	0.52	1.71
32	19.9	0.66	2.17	0.68	2.23	0.39	1.28
36	22.4	0.59	1.94	0.59	1.94	0.24	0.79
40	24.9	0.36	1.18	0.34	1.12	0.13	0.43
44	27.3	0.23	0.75	0.22	0.72	0.03	0.10
48	29.8	0.11	0.36	0.09	0.30	0	0
48.9	30.4					0	0
52	32.3	0.02	0.07	0	0	0	0
52.1	32.4			0	0	0	0
52.5	32.6	0	0	0	0	0	0

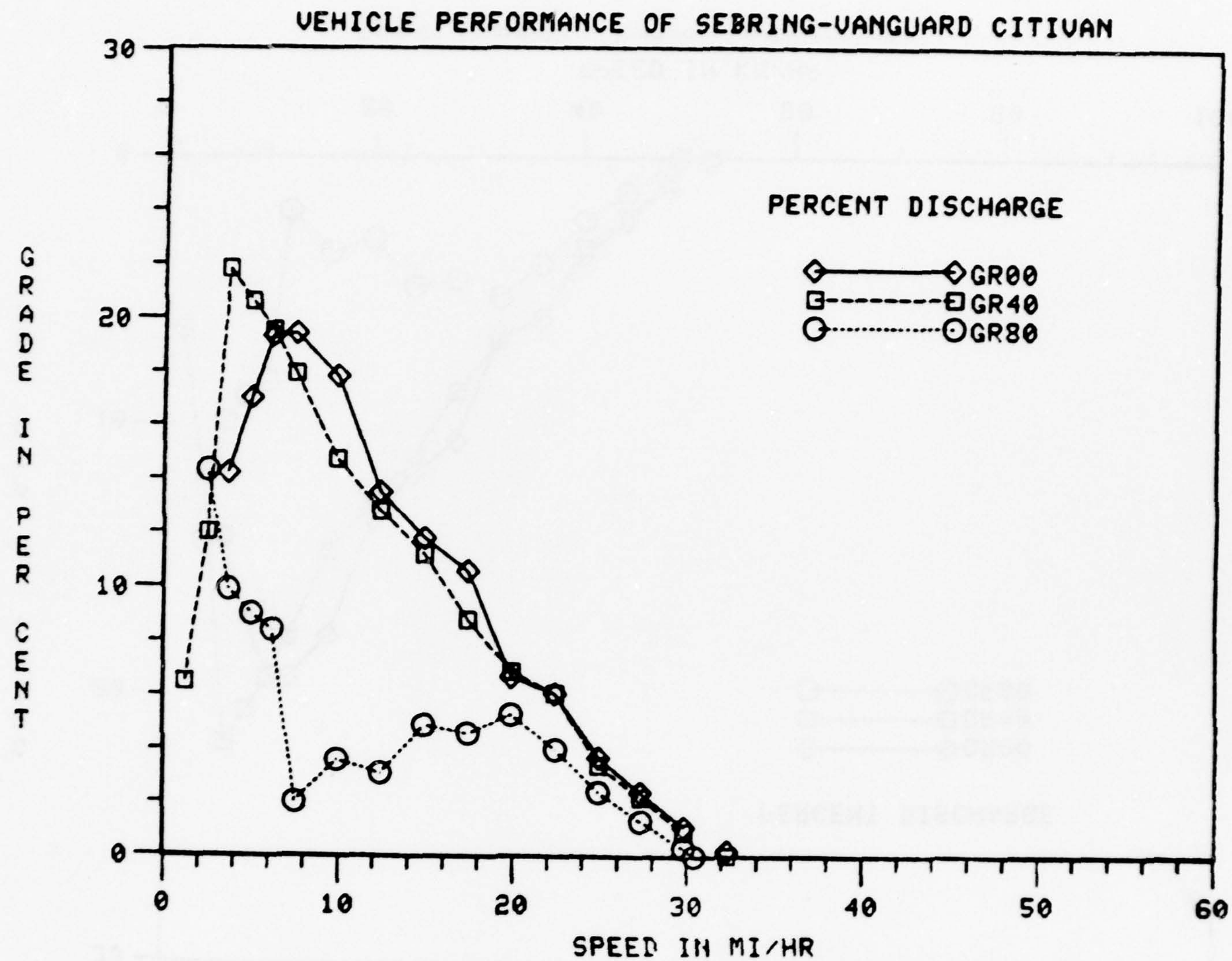


Figure 6A. Gradeability as a Function of Speed (English Units).

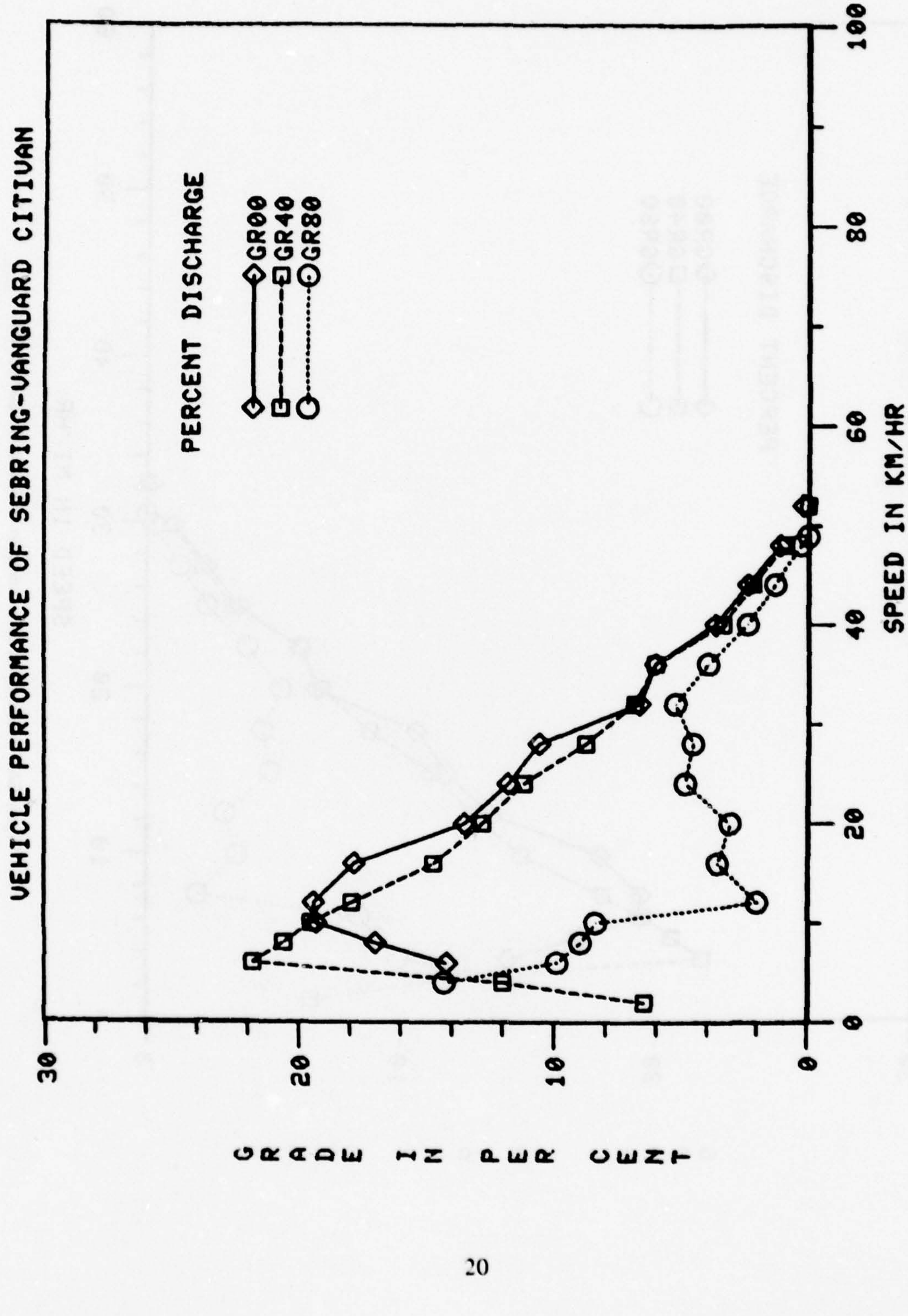


Figure 6B. Gradeability as a Function of Speed (Metric Units).

Table 6. Gradeability at Speed as a Function of Battery State of Charge

Vehicle Speed		Battery State of Charge		
		0% Discharge	40% Discharge	80% Discharge
		Gradeability Percent		
km/h	mi/h	%	%	%
0				
2	1.24		6.5	
4	2.5		12.0	14.3
6	3.7	14.2	21.8	9.9
8	5.0	17.0	20.6	9.0
10	6.2	19.3	19.5	8.4
12	7.5	19.4	17.9	2.0
16	9.9	17.8	14.7	3.6
20	12.4	13.5	12.8	3.1
24	14.9	11.8	11.2	4.9
28	17.4	10.6	8.8	4.6
32	19.9	6.7	6.9	5.3
36	22.4	6.1	6.1	4.0
40	24.9	3.7	3.4	2.4
44	27.3	2.4	2.2	1.3
48	29.8	1.1	0.9	3
48.9	30.4			0
52	32.3	2	0	

where:

V = vehicle speed in kilometers per hour (mi/h).

t = time, sec.

The results for the road energy determination are shown in Figures 7A, B, and C and Table 7.

Table 7. Road Energy Consumption

Vehicle Speed		Road Energy		
km/h	mi/h	MJ/km	kWh/km	kWh/mi
47.14	29.3	0.29	0.08	0.13
36.04	22.4	0.23	0.063	0.10
25.90	16.1	0.20	0.056	0.09
18.18	11.3	0.16	0.045	0.075
12.71	7.9	0.14	0.039	0.061
8.36	5.2	0.14	0.039	0.060

5. **Road Power Requirements.** The road power is a measure of vehicle aerodynamic and rolling resistance plus the differential, drive shaft, and a portion of the transmission's power loss.

The road power, P_n, required to propel a vehicle at various speeds is also determined from the coast-down tests. The following equations are used:

$$P_n = 3.86 \times 10^{-5} W \frac{V^2_{n-1} - V^2_n}{t_n - t_{n-1}}, \text{ kW}$$

or in English units

$$P_n = 6.08 \times 10^{-5} W \frac{V^2_{n-1} - V^2_n}{t_n - t_{n-1}}, \text{ hp}$$

The results of road power calculations are shown in Figures 8A and 8B and Table 8.

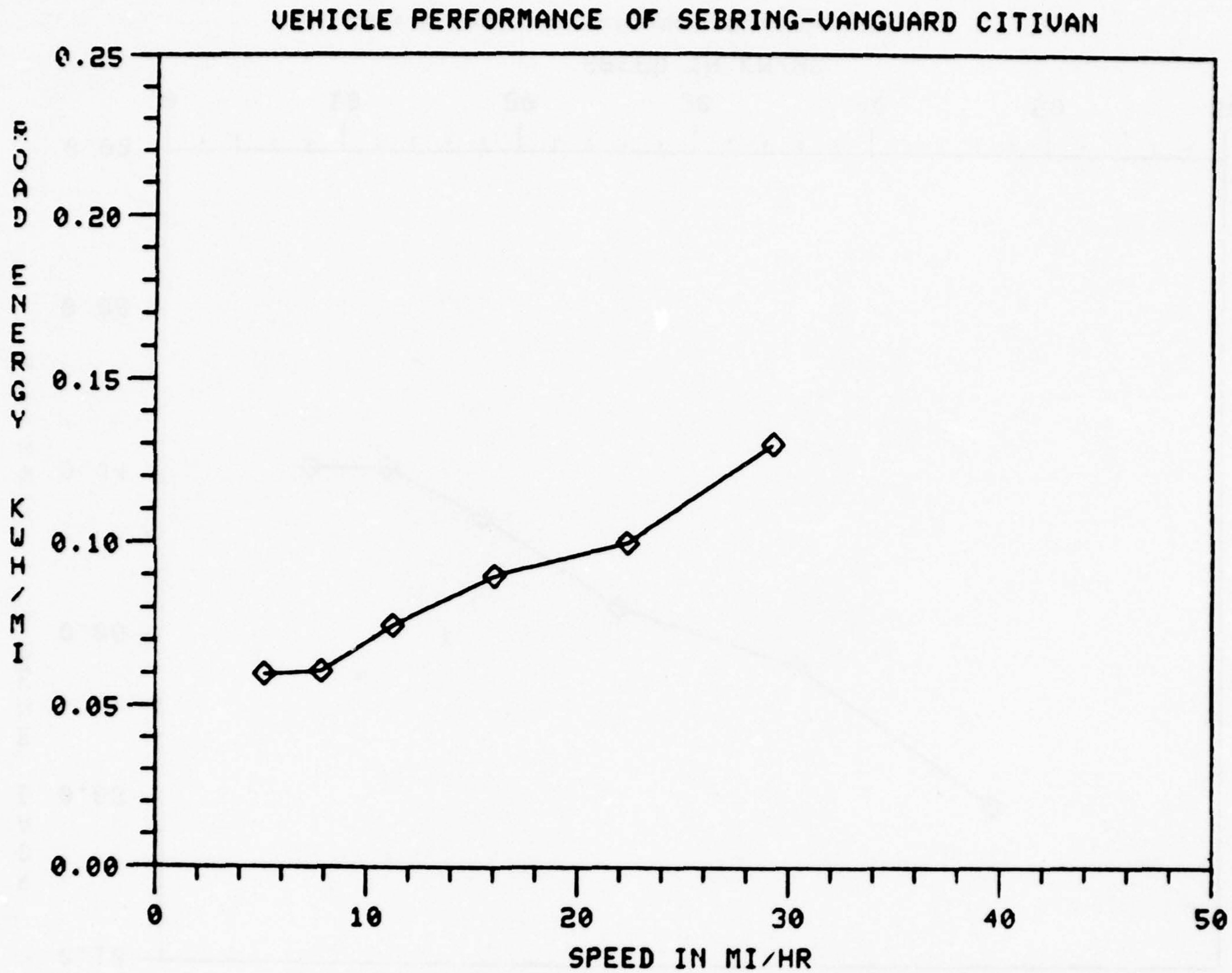


Figure 7A. Road Energy as a Function of Speed (English Units).

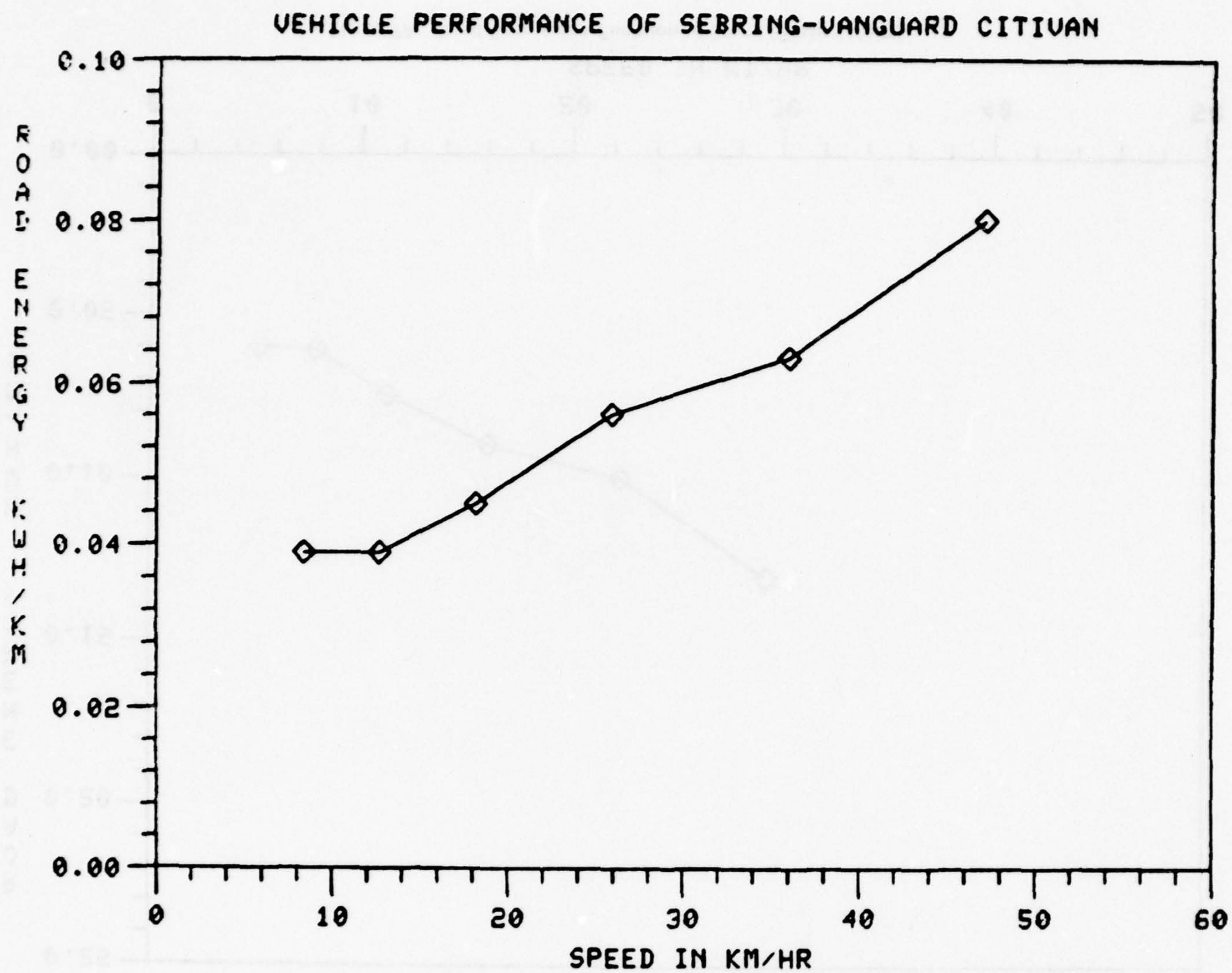


Figure 7B. Road Energy as a Function of Speed (Metric Units).

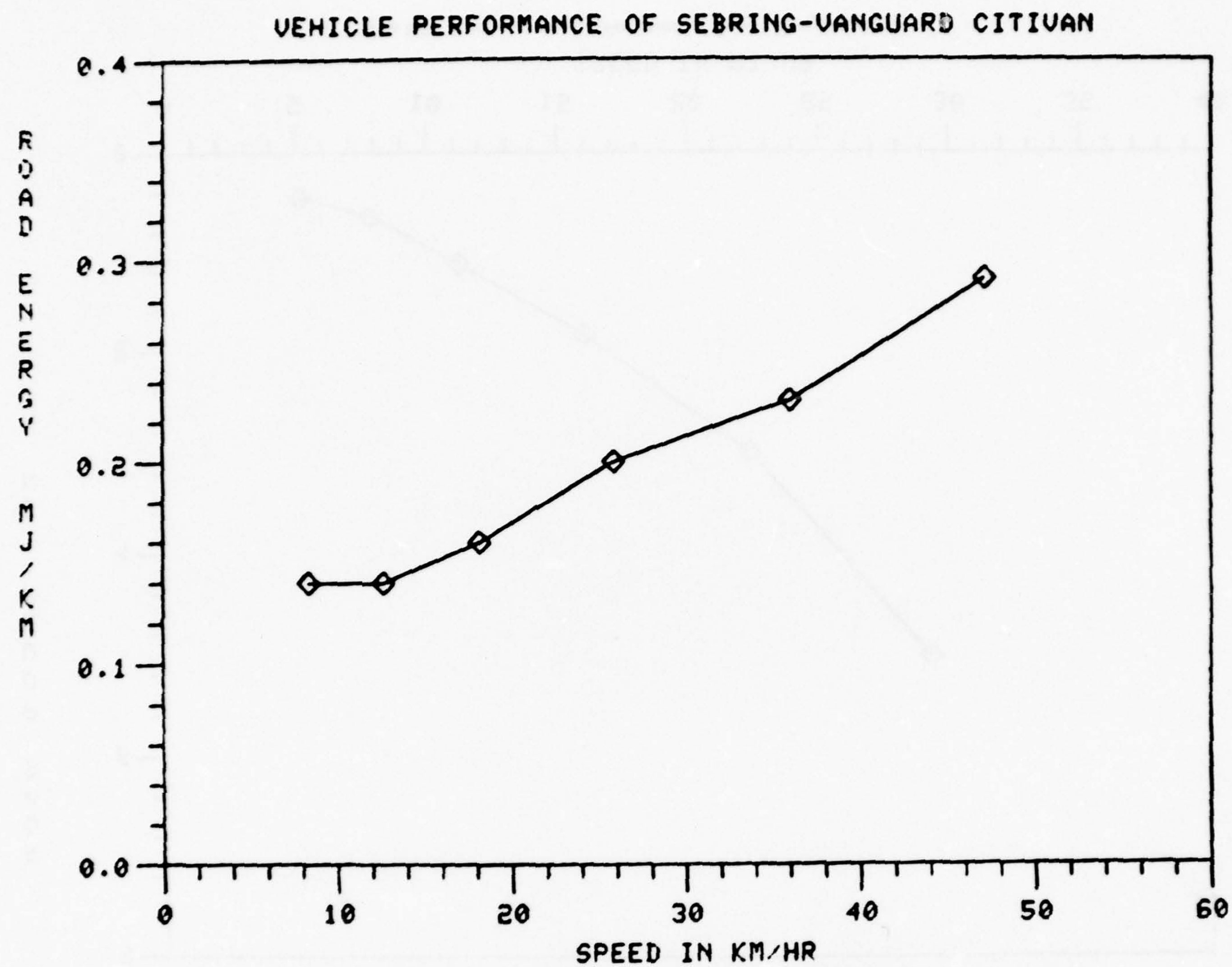


Figure 7C. Road Energy as a Function of Speed (Metric Units).

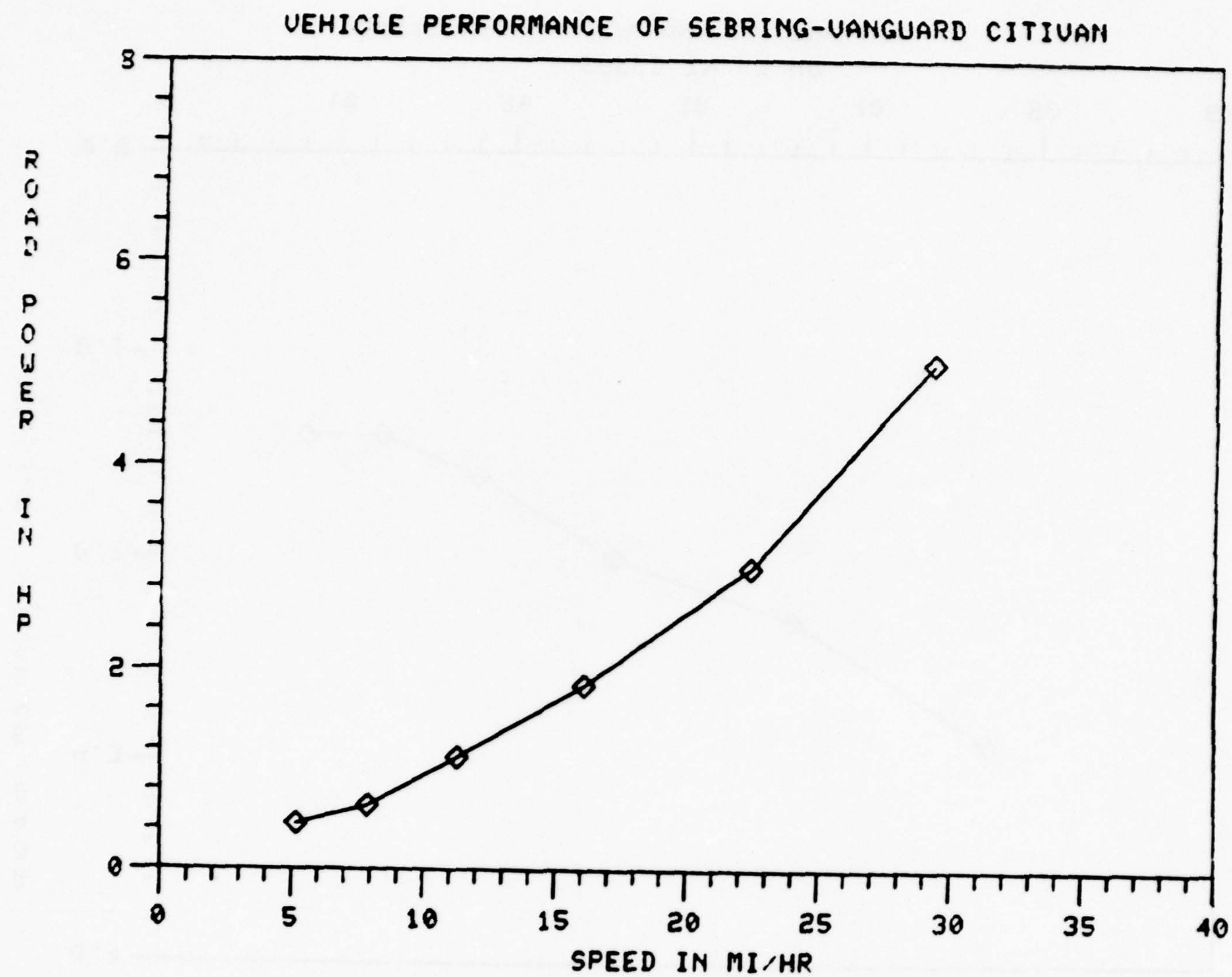


Figure 8A. Road Power as a Function of Speed (English Units).

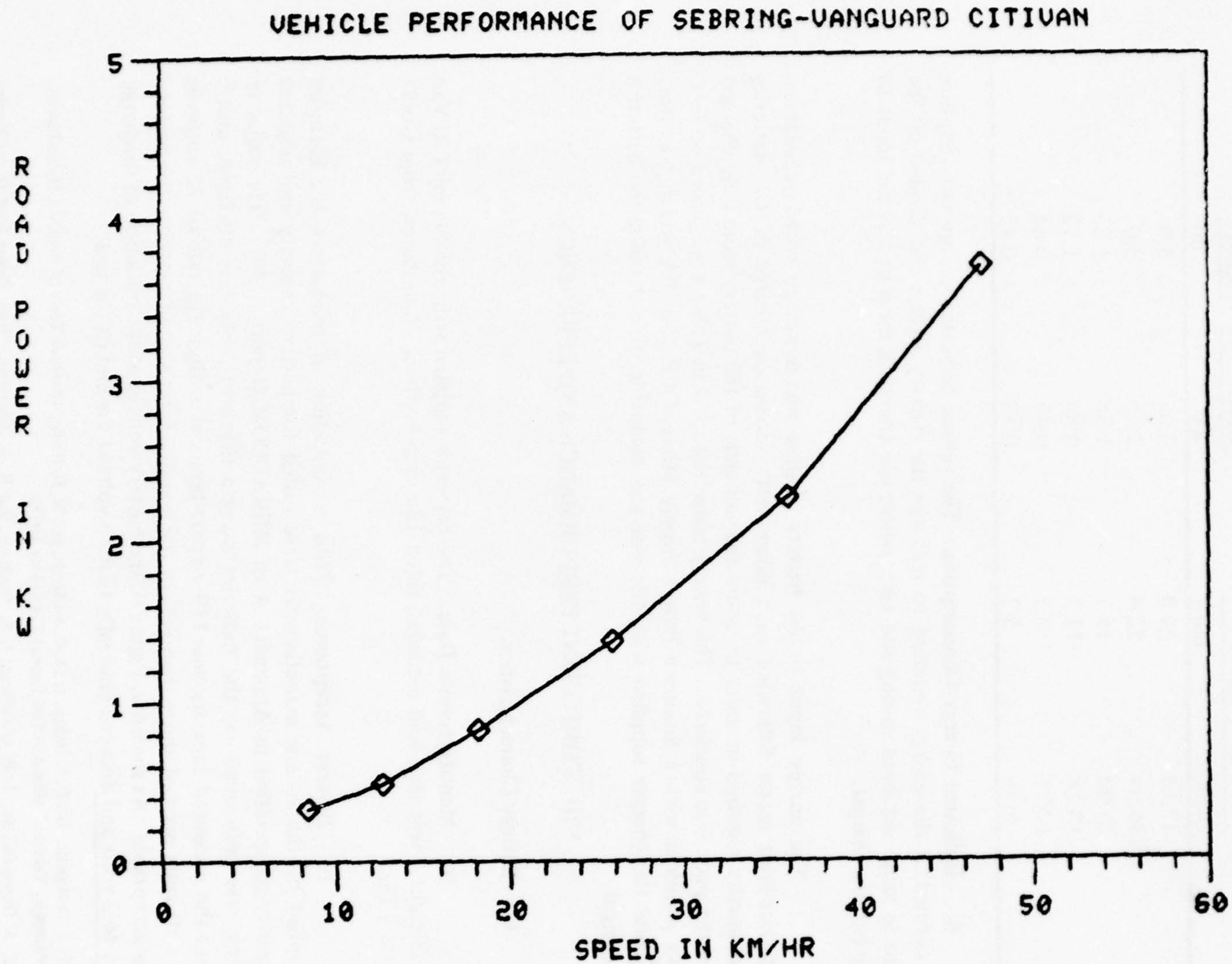


Figure 8B. Road Power as a Function of Speed (Metric Units).

Table 8. Road Power Requirements

Vehicle Speed		Road Power Required	
km/h	mi/h	kW	hp
47.14	29.3	3.68	5.0
36.04	22.4	2.26	3.0
25.90	16.1	1.38	1.85
18.18	11.3	0.83	1.13
12.71	7.9	0.49	0.64
8.36	5.2	0.33	0.45

6. Indicated Energy Consumption. The vehicle indicated energy consumption is defined as the energy required to recharge the battery after a test divided by the vehicle range achieved during the test, where the energy is measured as the input to the battery charger.

The energy input to the battery charger was measured with a residential kilowatt-hour meter following each range test. Some overcharge of the batteries was usually required in order to assure that all cells of the battery were fully charged and the pack was equalized. The energy usage reported in Table 1 was based on field data acquired with a Sorensen Power Supply Model DCR-150-10A which was used because the charger supplied with the van was incapable of recharging the batteries overnight.

VIII. COMPONENT PERFORMANCE AND EFFICIENCY

1. Battery Characteristics.

a. Manufacturer's Data. The batteries supplied with the Sebing Citi-Van were eight 6-volt lead-acid modules, rated 132 amp-hours at 75 amperes, from Gould Battery Co.

b. Battery Acceptance. Prior to initiation of road tests, the batteries supplied by the vehicle manufacturer were tested for battery capacity and terminal integrity as specified in Appendix A of MERADCOM Report 2244.[5] The capacity check was performed on the batteries using a thyristor-controlled discharge unit.[6] Since the measured capacity was 119 ampere-hours at a discharge rate of 75 amperes to 1.70 volts per cell, more than 80% of the manufacturer's rated capacity, the battery was acceptable. As shown in Figure 9, the battery voltage at the initiation of discharge was 46.2 volts and decayed gradually to 40.8 volts at the end of the test.

[5] E. J. Dowgiallo, Jr.; C. E. Bailey, Jr.; I. R. Snellings; and W. H. Blake; "Baseline Tests of the EVA Metro Electric Passenger Vehicle," MERADCOM Report 2244 (July 1978).

[6] E. J. Dowgiallo, Jr.; J. B. O'Sullivan; I. R. Snellings; and R. B. Anderson; "High Power Facility for Testing Electrochemical Power Sources," Princeton, New Jersey; *Journal of the Electrochemical Society*, Vol. 121, No. 9, Sep 74.

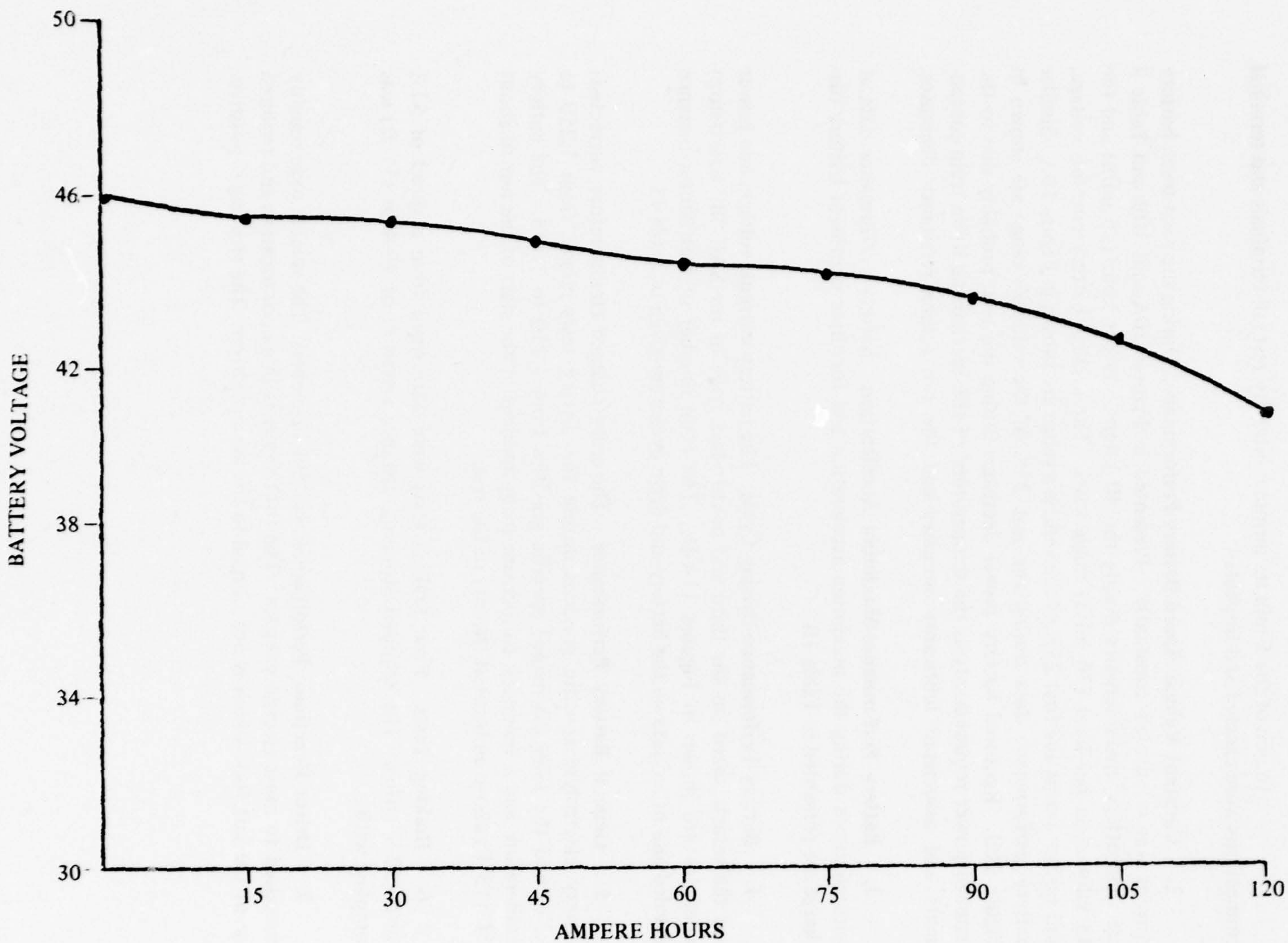


Figure 9. Battery Voltage as a Function of Capacity Removed.

In lieu of the 5-minute terminal integrity test, all terminals and terminal connections were cleaned and inspected.

2. **Constant Vehicle Speed Battery Performance.** During the road tests, battery current was monitored constantly. Presented in Figures 10A and 10B and Table 9 are the battery characteristics during the 40 kilometers per hour (25 mi/h) and the 48 kilometers per hour (30 mi/h) range tests. The average battery current, voltage, and power during the first 25% of the vehicle's range are shown in Figure 10A. Similar battery performance data during the last 25% of the vehicle's range are shown in Figure 10B. Required battery power decreases during the test, probably due to the reduced power requirements as the temperature of the mechanical drive train components and associated lubricants increases and the tire rolling resistance decreases.

3. **Battery Performance-Maximum Acceleration.** Battery performance data at selected times during the maximum acceleration test for three depths of battery discharge are presented in Table 10.

4. **Battery Performance-Driving Cycle.** The battery current, voltage, and power and the vehicle speed for the third and next-to-last cycle of the SAE "B" (start/stop) schedules are shown in Figures 11A-D. The total number of start/stops, distance traveled and other data on the battery and drive cycles are given in Table 11.

5. **General Battery Performance.** The fully charged (temperature corrected) battery electrolyte specific gravities during the driving tests ranged from 1.250 to 1.270 and the fully discharged specific gravities from 1.110 to 1.115. The battery temperature had a tendency to increase from ambient at the start of the test to about 7°C (13°F) above ambient at the end of the test.

6. **Braking Tests.** Four braking tests were performed from a speed of 52.8 km/h (32.8 mi/h). The required stopping distance criterion of 17.4 m (57 ft) was complied with.

7. **Driver Reaction.** Performance was fair in general. The vehicle rode roughly compared to most electric vehicles. The foot brake is in a poor location and required use of the left foot which is not normal to the average driver. The steering is positive.

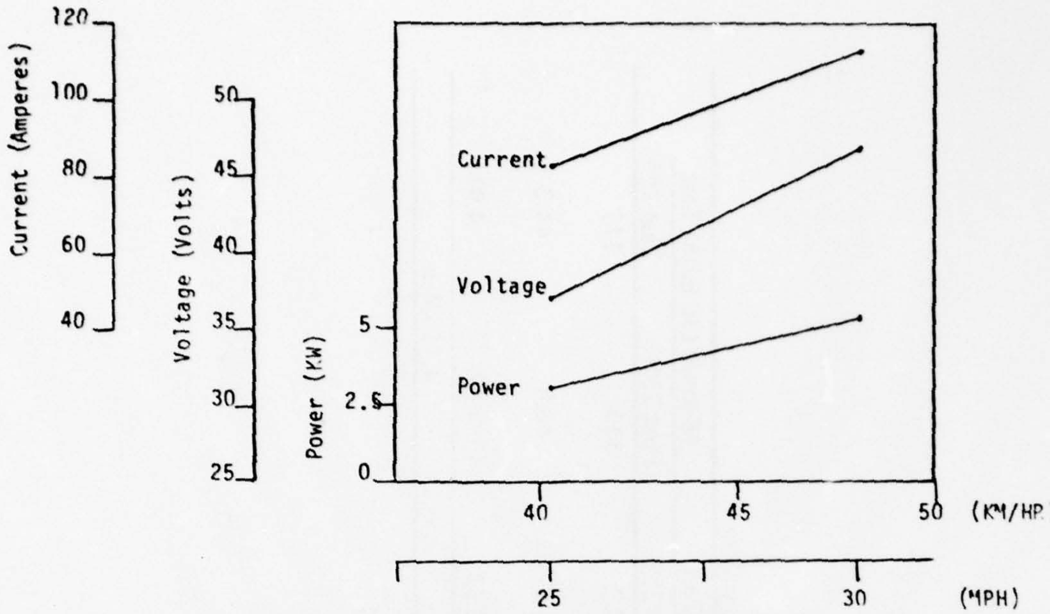


Figure 10A. Constant Speed Battery Performance (First 25% of Range).

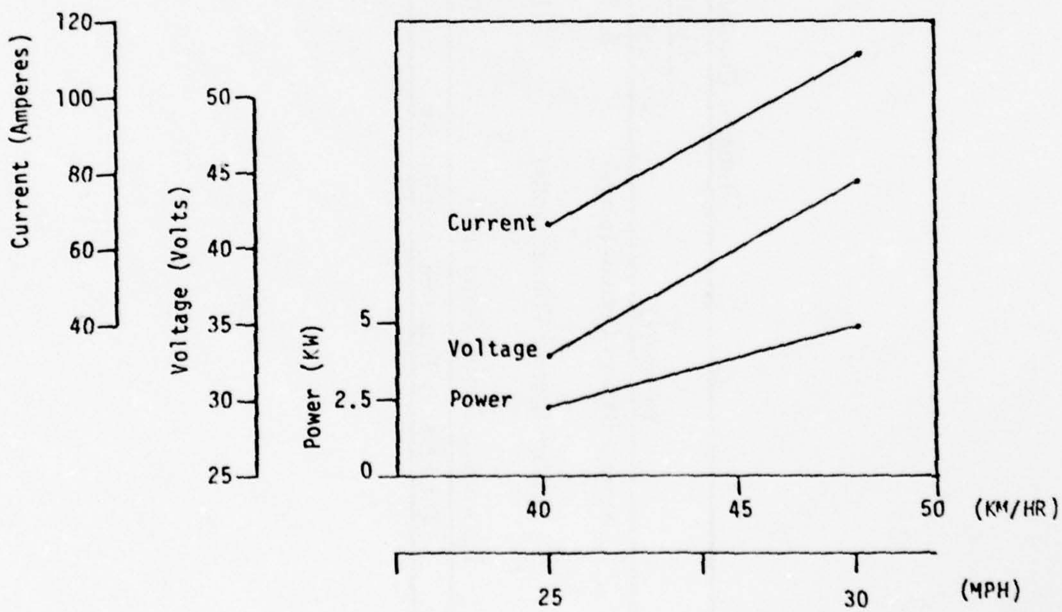


Figure 10B. Constant Speed Battery Performance (Last 25% of Range).

Table 9. Constant Speed Battery Data

Parameter	40-km/h (25 mi/h) Test		48-km/h (30 mi/h) Test	
	First 25%	Last 25%	First 25%	Last 25%
$\overline{I}_B$ Average Battery Current (amps)	83.5	67.2	113	111
$\overline{V}_B$ Average Battery Voltage (volts)	37.1	33.1	46.8	44.2
$\overline{P}_B$ Average Battery Power (kW)	3.09	2.22	5.29	4.91
Total Energy Removed from Battery	3.69 kW-h		4.75 kW-h	

Table 10. Battery Performance – Maximum Acceleration

Time (s)	Speed (mi/h)	km/h	Current (Amp)	Voltage (v)	Power (kW)	Discharged (%)
3	11.4	18.3	497	37.9	18.8	0
10	24.0	38.7	206	44.3	9.1	0
20	29.5	47.5	135	46.0	6.2	0
30	31.4	50.6	117	46.6	5.5	0
40	32.3	51.7	110	46.8	5.1	0
60	32.6	52.5	105	47.0	4.9	0
3	7.5	12.0	543	35.1	19.1	40
10	22.4	36.0	228	42.9	9.8	40
20	28.8	46.3	136	45.0	6.1	40
30	30.7	49.4	115	45.6	5.2	40
40	31.6	50.9	108	45.7	4.9	40
60	32.4	51.1	105	45.8	4.8	40
3	7.1	11.4	524	32.4	17.0	80
10	11.3	18.1	366	35.4	13.0	80
20	20.9	33.7	183	41.5	7.6	80
30	27.0	43.5	136	42.8	5.8	80
40	29.1	46.9	115	43.3	5.0	80
60	30.4	49.0	104	43.7	4.5	80

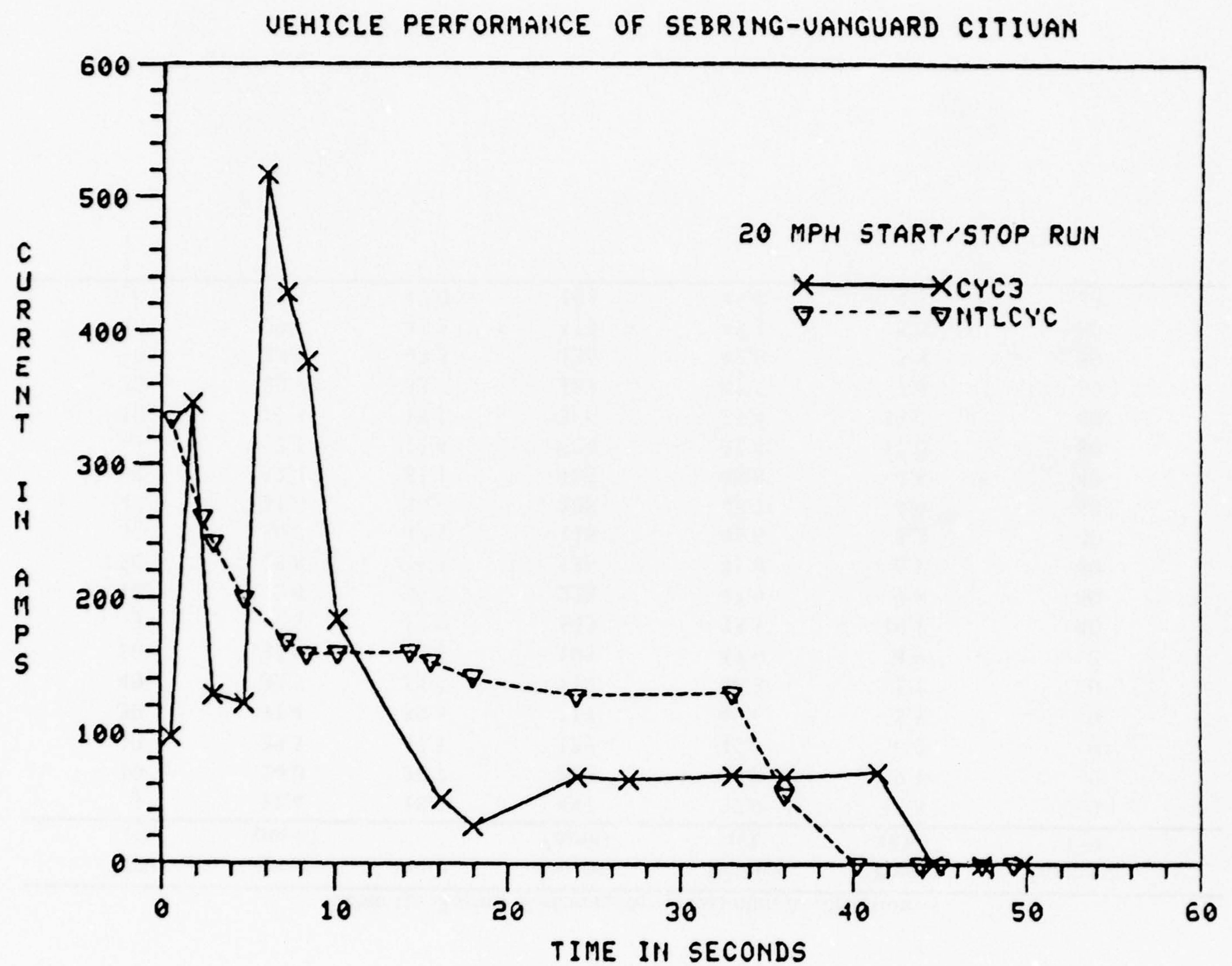


Figure 11A. Average Battery Current.

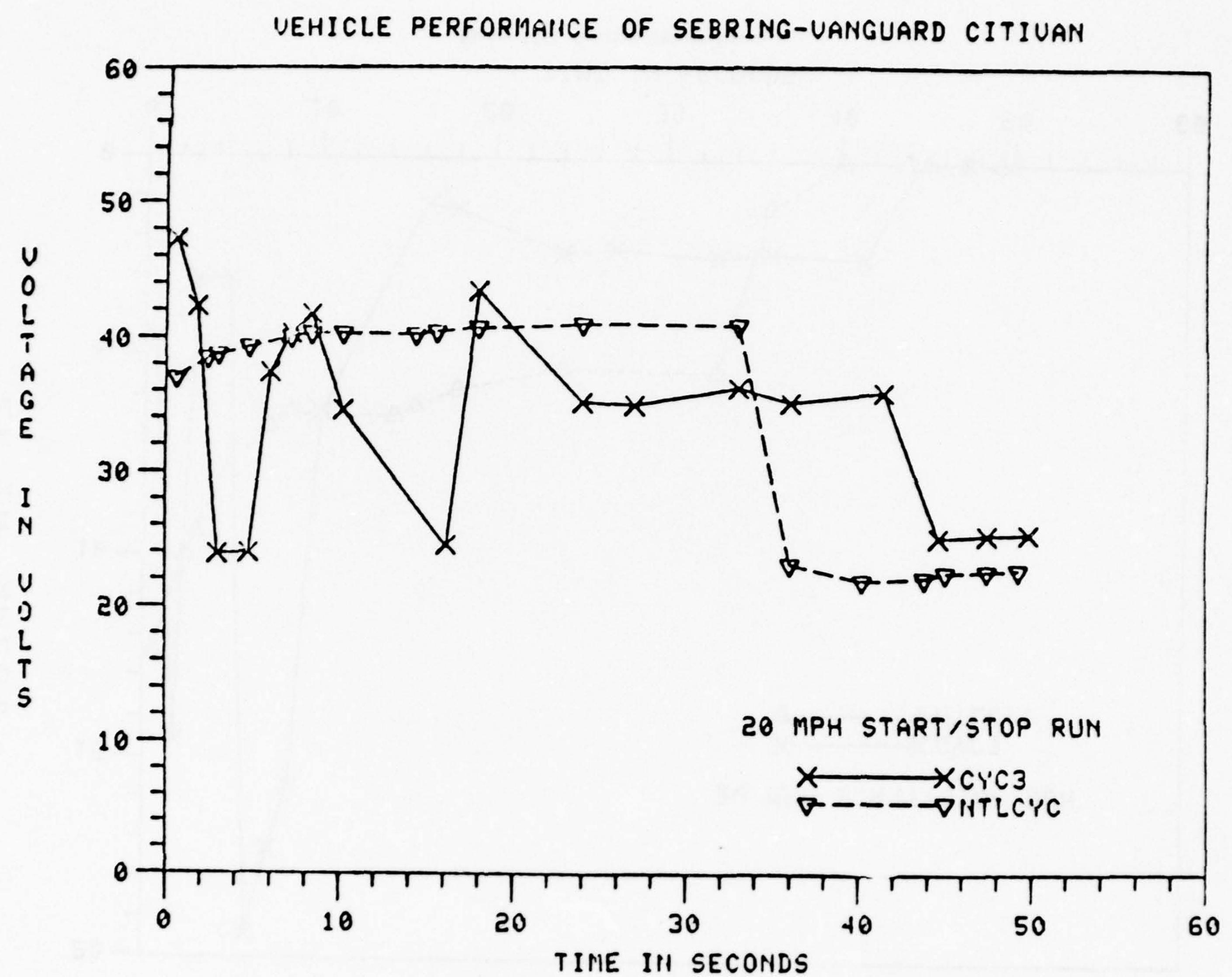


Figure 11B. Average Battery Voltage.

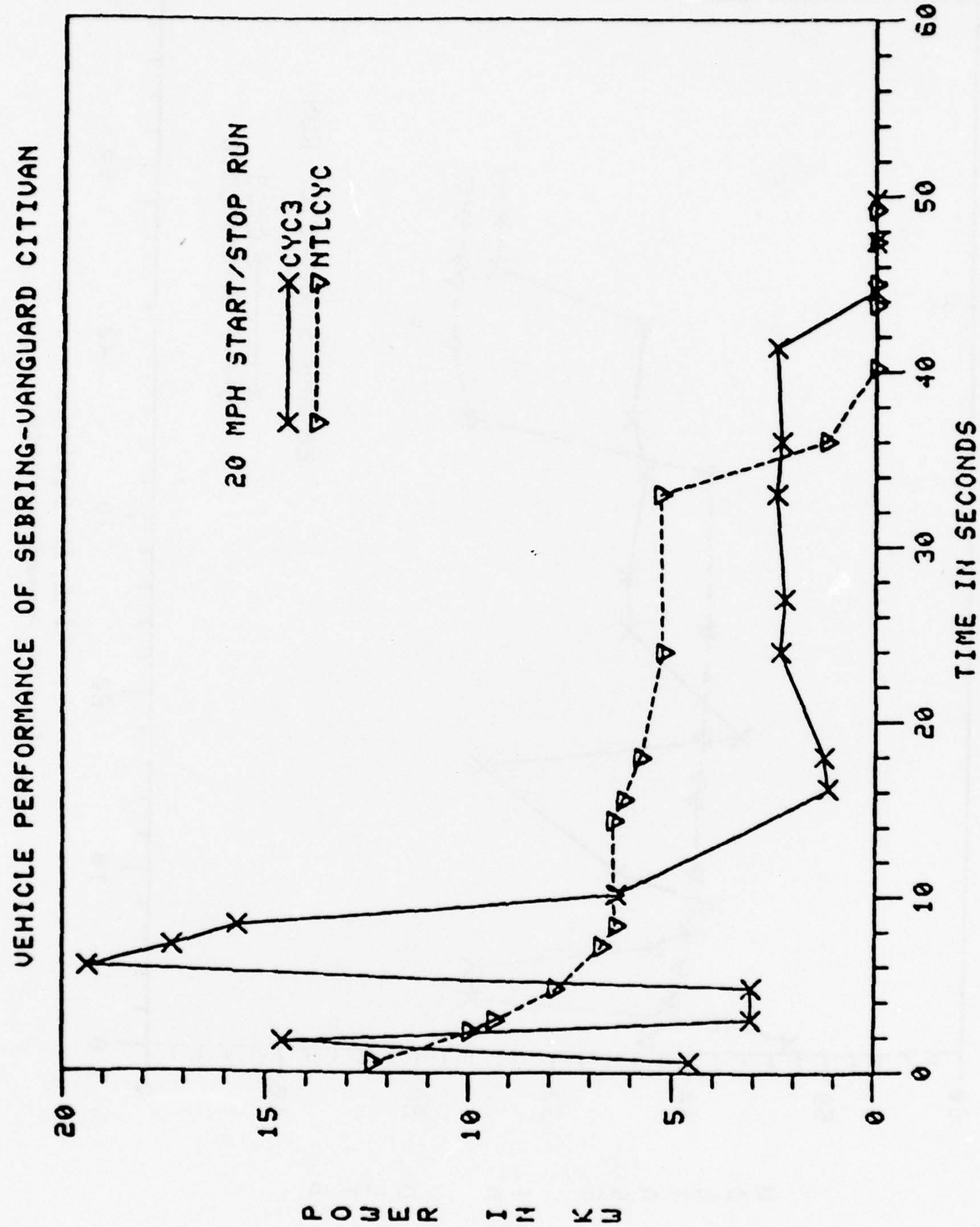


Figure 11C. Average Battery Power.

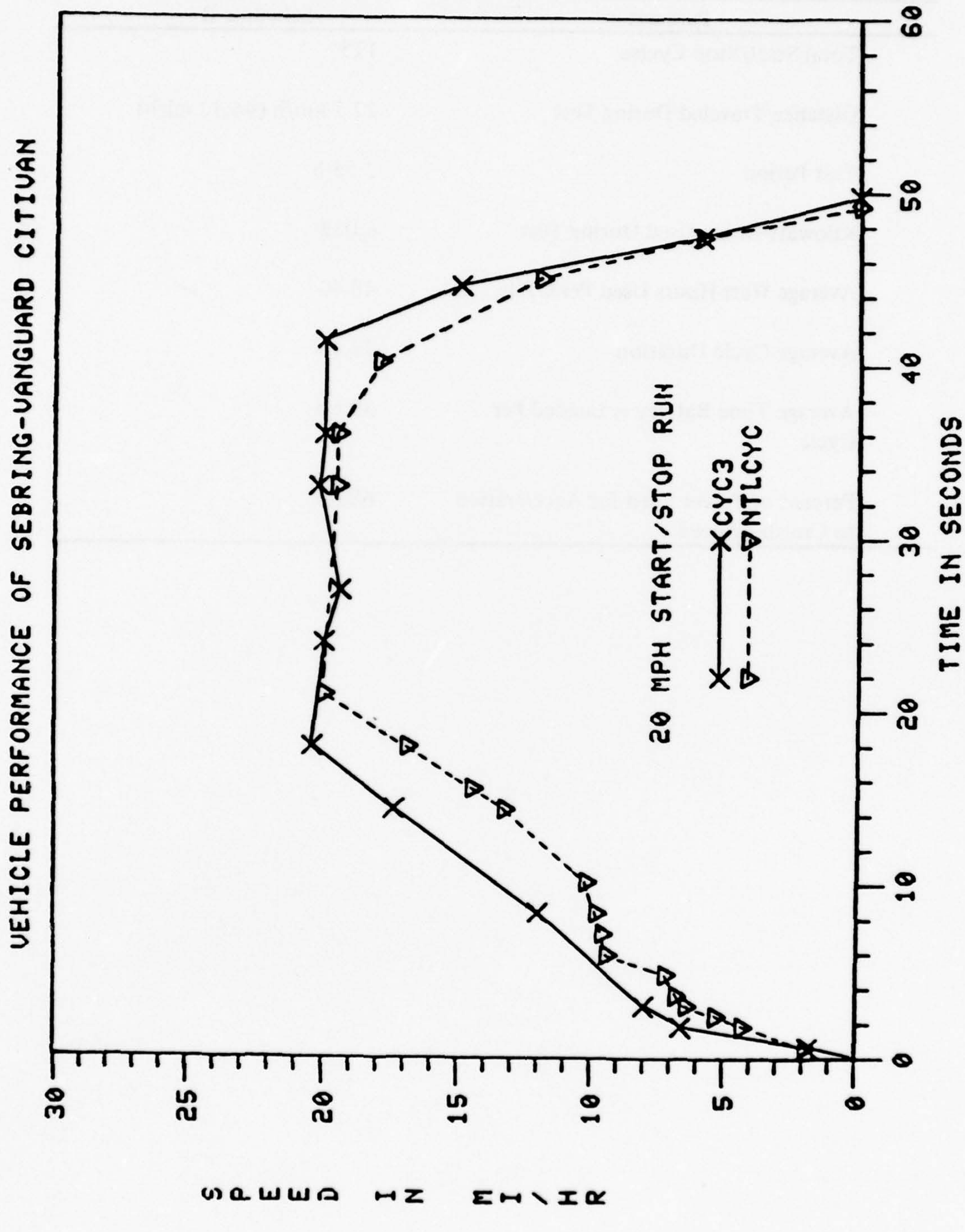


Figure 11D. Speed as a Function of Time.

Table 11. Driving Cycle Performance

Parameter	Schedule B
Total Start/Stop Cycles	125
Distance Traveled During Test	27.7 km/h (44.32 mi/h)
Test Period	2.55 h
Kilowatt-Hours Used During Test	6,052
Average Watt-Hours Used Per Cycle	48.40
Average Cycle Duration	73.4 s
Average Time Battery is Loaded Per Cycle	39.6 s
Percent of Power Used for Acceleration to Cruising Speed	68.0%

APPENDIX A

VEHICLE SUMMARY DATA SHEET

1. Vehicle Manufacturer:
   Sebring-Vanguard, Inc.
   Sebring, Florida 33871

2. Vehicle Description:
   Name: Citi-Van
   Model: 611SN0003
   Price: $3,988.00

3. Vehicle Weight:
   Curb Wt: 660.57 kg (1,455 lb)
   Driver Wt: 88.98 kg (196 lb)
   Gross Wt: 884.85 kg (1,949 lb)
   Passengers Wt: 84.44 kg (186 lb)
   Payload Wt: 50.85 kg (112 lb)

4. Vehicle Size:
   Wheelbase: 1.93 m (76 in.)
   Width: 1.42 m (56 in.)
   Legroom: 0.56 m (22 in.)
   Length: 2.74 m (108 in.)
   Headroom: 0.91 m (36 in.)

5. Auxiliaries & Options:
   No. Lights: 16

   a. 2 Head Lamps
   b. 8 Parking Lamps
   c. 4 Signal Lamps
   d. 1 Back-Up Lamp
   e. 1 Dome Lamp

Windshield Wipers	Yes	Windshield Washers:	Yes
Defroster:	Yes	Heater:	Yes
Radio:	No	Fuel Gage:	Yes
Ammeter:	No	Tachometer:	Yes
Speedometer:	Yes	Odometer:	Yes
Number of Mirrors:	One	Power Steering:	No
Power Brakes:	No		

Transmission Type: Direct Pinion Drive

6. Propulsion Batteries:
   - Type: Lead Acid
   - No. of Modules: 8
   - No. Cells: 24
   - AH Capacity: 132.5
   - Battery Wt: 210.6 kg (464 lb)
   - Battery Rate: 75 A
   - Manufacturer: Globe Union
   - S/N: None
   - Battery Voltage: 24 - 48
   - Battery Size: 180 mm x 250 mm x 240 mm (7 in. x 10 in. x 9.5 in.)

7. Auxiliary Battery:
   - Type: Power Breed
   - No. Cells: 6
   - AH Capacity: 4
   - Battery Rate: 20 h
   - Manufacturer: Gould
   - Battery Voltage: 12
   - Battery Wt: 19.07 kg (42 lb)

8. Controller:
   - Type: Multi-Voltage Resistive Relay
   - Size: 400 mm x 160 mm x 190 mm (16 in. x 6.5 in. x 7.5 in.)
   - Manufacturer: Vanguard
   - Current Rating: 150A
   - Weight: 8.17 kg (18 lb)

9. Propulsion Motor:
   - Type: Series Wound
   - Insulation Class: Fon Plate
   - Current Rating: 130 A
   - Weight: 21.56 kg (47.5 lb)
   - Rated Speed: 4100 r/min
   - Manufacturer: GE
   - Voltage Rating: 48 V
   - HP Rating: 6
   - Size: 270 mm L, 16 mm dia (10.75 in. L, 6.5 in. dia)

10. Body:
    - Type: Cyolac
    - No. Doors: 3
    - No. Windows: 6
    - No. Seats: 1
    - Cargo Volume: 1.36 m^3
    - Manufacturer: ABS
    - Type: Hinge
    - Type: 4 glass, 2 plastic
    - Type: Bench
    - Cargo Dimensions: 610 mm x 810 mm x 910 mm (24 in. x 32 in. x 36 in.)

11. Chassis:
    - Type Frame: Boxed Rectangular
    - Type Material: Aluminum
    - Type Springs: Leaf
    - Axle Type Front: Pipe
    - Axle Manufacturer: Sebring-Vanguard
    - Manufacturer: Sebring-Vanguard
    - Modifications: None
    - Type Shocks: Standard
    - Axle Type Rear: Direct Gear Drive

Drive Line Ratio: 7.1 : 1
Type Brake Front: Drum
Type Brakes Rear: Drum
Regenerative Brakes: No
Tire Type: Radial
Size: 125SR12
Rolling Radius: 244 mm (9.8 in.)

Manufacturer: MICHELIN
Pressure: 32 lb/in.^{2}

12. Battery Charger:
On or Off Board: On
Automatic Turn Off: No

Manufacturer: Symons
Input Voltage: 115
Recharger Timer: No

APPENDIX B

DESCRIPTION OF VEHICLE TEST TRACK

The test site used to conduct the tests described in this report is located at Aberdeen, Maryland. The track is owned and operated by the US Army. Three test sites were used.

1. **Gradeability Slopes.** Gradeability of vehicles is a basic characteristic usually given in design specifications of military vehicles. The Munson gradeability slopes (Figures B1 and B2) cover a range of 5 to 60 percent. They are used to determine optimum drive ratios and maximum attainable speeds on each slope, as well as brake-holding ability and adequacy of angles of approach and departure. With the test vehicle in both ascending and descending attitudes, functions such as lubrication, fuel flow, and carburetion are investigated. The effect of unbalance on turret traversing efforts and functioning of turret drive systems may also be studied on the slopes. The 5, 10, 15 and 20 percent slopes, approximately 14 feet wide, are paved with asphalt; the 30, 40, 45, 50 and 60 percent slopes, with concrete.

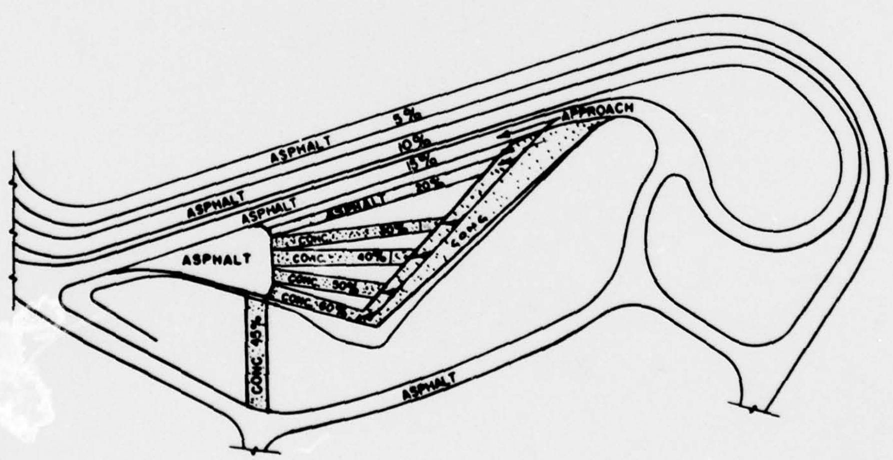


Figure B1. Plan View of Slopes.

Figure B2. Eight of the Standard Gradeability Slopes.

2. **Mile Loop**. The Mile Loop (Figure B3) was originally constructed in 1933 as a level concrete course of oval shape for continuous high speed operating tests of vehicles. Near the headquarters area of the post, the course consists essentially of two straight sections, each one-quarter-mile long, joined at each end by quarter-mile sections of regular curvature to form an oval of 1 mile total circumference.

Figure B3. Aerial View of Mile Loop.

The course has been modified by covering and maintaining the surface with hot-mixed bituminous concrete and by the addition of a gravel surface parallel to and outside the oval. Several facilities also have been added in the area: a winch test facility, a "pothole-crosstie" course for forklift truck testing, and a 1-inch bump course for mobility testing of towed vehicles.

Winch Test Facility (Mile Loop). This winch facility has a restraining capability of 100,000 pounds and is used primarily as an anchor during winch endurance testing.

3. **Dynamometer Course.** The Dynamometer Course (Figure B4) is located in the Michaelsville section of the proving ground, 4 miles from the headquarters area. Constructed of reinforced concrete, with a hot-mixed bituminous surface, it is suitable for the operation of the heaviest tracklaying vehicles.

The course has a total gradient of less than 0.1 percent in its 1-mile length, and turnarounds are provided at each end. It is used for closely controlled engineering tests such as drawbar pull and tractive resistance measurements, acceleration and braking tests, and fuel consumption measurements.

Figure B4. Dynamometer Course.

1 – No. 1 Cross-Country
2 – No. 2 Cross-Country
3 – No. 3 Cross-Country
4 – No. 4 Cross-Country
5 – Secondary Road A
6 – Secondary Road B
7 – 3-Mile, High Speed Road
8 – Mud Bypass Course
9 – Mud Mobility Course
10 – Mobile Bridge Test Facility
11 – Deep Water Fording Facility
12 – Swamp Quarter Mobility Area
13 – Crash Barrier
14 – Shop Area

Figure B5. Aerial View of Perryman Test Area.

APPENDIX C

VEHICLE PREPARATION AND TEST PROCEDURE

When a vehicle was first received at MERADCOM, a number of checks were made to assure that it was ready for performance tests. These checks were recorded on a vehicle preparation check sheet. The vehicle was examined for physical damage upon arrival. Before operating the vehicle, a complete visual check was made of the entire vehicle. The battery was charged and specific gravities taken to determine if the batteries were equalized. If not, an equalizing charge was applied to the batteries. The integrity of the internal interconnections and the battery terminals were checked by drawing 300 amps or the vehicle manufacturer's maximum allowed current from the battery for 5 minutes; if the battery terminals or interconnections temperature rose more than 60°C above ambient, the test was terminated and the terminals cleaned or battery replaced. The batteries were recharged and a battery capacity check was made. This test was made in accordance with the battery manufacturer's recommendations. To pass this test, the capacity had to be within 20% of manufacturer's published capacity at the published rate.

When a vehicle arrived at a test site (APG), a number of checks were performed to assure that it was ready for performance testing. The wheel alignment was checked, compared, and corrected to the manufacturer's recommended alignment values. The vehicle was weighed and compared with the manufacturer's specified curb weight. The gross vehicle weight was determined by manufacturer's rated payload.

TEST PROCEDURE

Each day, before a test, a number of pretest checks were made and entered on the vehicle data sheet. These data included:

1. Average specific gravity before and after test.
2. Tire pressures.
3. Fifth-wheel tire pressures.
4. Weather information.
5. Battery temperatures.
6. Test start time.
7. Test termination time.
8. Amp hours out of the battery.
9. Fifth-wheel distance count.

10. Odometer reading before and after each test.
11. A.C. kW used for recharge.
12. D.C. amp hours into battery on recharge.

To prepare for a test, the specific gravities are first measured and recorded. The tire pressures are measured. The instrumentation is connected and power from the instrumentation battery is applied. All instruments are turned on and warmed up and all data channels are calibrated. The vehicle is towed to the starting point on the track. Weather data are recorded; odometer reading taken. The test is started and is carried out in accordance with the DOE test and evaluation procedure. When the test is terminated, the test team makes all the proper checks and records all data on data test sheet for the day's test. After all checks are made, vehicle is towed back to the charge station and placed on charge for next day's test.

WEATHER DATA

Measurements of wind velocity and direction and ambient temperatures were taken at the beginning and at the end of each day's testing. The APG Airport weather station was used for all weather data.

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